Proceedings
-1949 C 15 1952
.3

LIBRARY
FISH & WILDLIFE SERVICE
PACIFIC OCEANIC FISHERY
INVESTIGATIONS

1949-
V.

Proceedings of the
Seventh Pacific Science Congress
of the
Pacific Science Association

Held at Auckland and Christchurch, New Zealand,
2nd February to 4th March, 1949

VOLUME III
METEOROLOGY AND OCEANOGRAPHY

WELLINGTON
R. E. Owen, Government Printer
1952

PERIODICAL

Pacific
Science
Congress.
Proceed.
7th
1949
V.3

~~DATE OF MAGAZINE~~	BORROWER'S NAME	TIME ~~KKK~~ out
OCT 18 1961	Austin	
	~~Mann~~	
NOV 15 1963	Bartholic	
7/24/65	[illegible]	

PERIODICAL

Pacific Science Congress.
Proceed.

7th
1949
V.3

LIBRARY
BUR. OF COMM. FISH.
HON. BIOL. LAB.

Proceedings of the

91

Seventh Pacific Science Congress

of the

Pacific Science Association

Held at Auckland and Christchurch, New Zealand,
2nd February to 4th March, 1949

1924 60

VOLUME III

METEOROLOGY AND OCEANOGRAPHY

WELLINGTON
R. E. Owen, Government Printer
1952

V.3
1949

CONTENTS

METEOROLOGY

Page

Symposium on General Meteorology of the Tropical Pacific 5

Symposium on General Meteorology of the Pacific in Temperate and Higher Latitudes 37

Symposium on Climatology of the Pacific Region 91

Symposium on Research Needs and Techniques in Pacific Meteorology .. 125

OCEANOGRAPHY

Reports of the Standing Committee on Oceanography 136

Reviews of Pacific Oceanography 164

Symposium on Underwater Sound and Its Biological and Oceanographical Applications 207

Symposium on Sedimentation and Characteristics of Sea Bottom in the Pacific Basin 209

Symposium on Physical and Chemical Properties of Pacific Ocean Waters .. 220

Symposium on Marine Biogeographical Provinces in the Pacific 305

Symposium on Problems of Bipolarity and of Pan-Temperate Faunas .. 324

Symposium on Problems of Eustatism in the Pacific Basin and Rim .. 331

Symposium on Wave Analysis and Wave Prediction : Waves and Tsunamis 360

Digitized by the Internet Archive
in 2026

https://archive.org/details/proceedings-of-the-seventh-pacific-science-congress-of-the_1949_3

METEOROLOGY

SYMPOSIUM ON GENERAL METEOROLOGY OF THE TROPICAL PACIFIC

SOLAR ACTIVITY AND AIR-PRESSURE FLUCTUATIONS OVER THE SOUTH PACIFIC OCEAN

By H. P. Berlage, Meteorological and Geophysical Service, Indonesia

The existence of an approximate three-year oscillation in the weather elements of the South Pacific and Indian Oceans is perhaps most clearly demonstrated by a graphical representation of the deviations from normal of the six-monthly overlapping means of air-pressure in the tropical low extending from South India to North Australia. Let us take as such the Batavia air-pressure curve (Fig. 1).

In previous publications I have tried to establish a theory of the successive strengthening and weakening of the air and water circulation in the South Pacific Ocean, which would explain the long-period oscillations considered here. I was led to this theory by three empirical facts—

(1) Temperature in our region fluctuates with air-pressure in parallel waves, however, showing a phase lag of seven months.

(2) Air-pressure in the permanent high-pressure region of the South Pacific Ocean centred at Easter Island and air-pressure in the region considered here oscillate in balance. If air-pressure is above normal in one region it is below normal in the other (Sir G. Walker).

(3) Low sea-surface temperatures in our region cause air-pressure to rise, high sea-surface temperatures cause air-pressure to fall.

The normal cycle which occurs is probably as follows: if air-pressure is abnormally high in the region Bombay–Darwin, it is abnormally low in the sub-tropic high of Easter Island. Consequently, the atmospheric circulation round this high is weakened. This causes the water circulation to be weakened also. The Humboldt current is weakened. Less cold water is driven northward along the west coast of South America. The south equatorial current is weaker and warmer than usual. Temperature in the seas of our region rises. Consequently air-pressure is lowered. Hence when air-pressure is abnormally low in the region Bombay–Darwin it is abnormally high in the sub-tropic high of Easter Island. So the balance has swung from one side to the other, and after another turn the cycle is closed.

Theory proves that if the phase-lag between temperature deviations and air-pressure deviations is seven months the period of the oscillation becomes four times seven, or twenty-eight months—that is, 2·3 years.

Now, this oscillation would experience the damping of every natural oscillation if it were not sustained by the continuous in-flow of energy from the sun. We may therefore expect that such oscillations as the air-pressure fluctuations at Batavia, here exhibited, will show the influence of the fluctuations in solar activity. We will not discuss here how the fluctuations in solar activity, which are hardly noticeable in the total radiation from the sun received at sea-level, may be strongly reflected in fluctuations of air-pressure as a consequence of motions induced in the higher atmospheric layers where the ultra-violet radiation is absorbed (B. Haurwitz). From a simple inspection of the Batavia air-pressure curve it is clear that air-pressure is depressed during years of many sunspots and rises higher and oscillates more freely during years of few sunspots.

I think the situation in its general outlines is clear. The earth possesses, like every oscillator, some fundamental period, perhaps it even shows two, but certainly not many. The sun influences the motion of this oscillator by its energy stream. The earth is like a violin, the sun is the player, its radiation is the bow. And the reason why the resulting music is not continuously the same tone is that the source of energy fluctuates so that the music reminds one of numerous variations on the same theme.

I found by trial and error that the fluctuations of air-pressure at Batavia can be reconstructed quite adequately by the application of the following rules :—

(1) A high-pressure year follows one, two, or three years after a sunspot minimum year. It appears whenever the sunspot number of the year surpasses 20. It appears three years after the previous high-pressure year, if 20 has not yet been reached. When in the first case the mean sunspot number surpasses 50, the impulse will be called strong.

(2) The next high-pressure year follows three, four, five, or six years later. It follows three years later if the mean sunspot number has not or not yet reached 81 or when the previous impulse was strong. It follows four, five, or six years later when the sunspot maximum has passed and the mean sunspot number has decreased below 81.

(3) The next high-pressure year follows two or three years later, two years later whenever the mean sunspot number has decreased below 54.

(4) The next high-pressure year follows two or three years later, two years later whenever the mean sunspot number has decreased below 13.

There are three points towards which I draw special attention :—

Firstly, as already noted by C. Braak, if the period of the oscillation is really three years the fall of the barometer evidently takes only one year, the rise, however, two years. This has been taken into account. The cause probably is that the heating of the south equatorial current when the big circulation is weakened occurs rather quickly, whereas the cooling actually requires the transport of polar water from great distances and is therefore late in showing its ultimate effect.

Secondly, between two maxima of air-pressure when separated by an interval greater than three years a secondary maximum is introduced.

Thirdly, there are two instances in which two successive years both show high pressure. The first instance is 1918–1919, rule 2 leaving the case dubious. The second instance is 1944–1945, the first of the rules indicating 1945 and rule 4 indicating 1944 as a high-pressure year. Evidently better can be achieved. However, leaving room for the great number of minor influences which may have disturbed the primary variation, it is astonishing to see how few discrepancies between the actual and the purely constructed curves remain which obviously call for special explanations. Such are, for instance, the eruption of Krakatoa in 1883 and Mount Katmai in 1912, which have caused noticeable disturbances in the more regular variation of air-pressure.

The above supports my view that this outstanding long-periodic terrestrial oscillation of nearly three years is almost completely controlled by solar action. This is an important conclusion as it may open the way towards an understanding of comparable pseudo-periodic variations in other parts of the world which so far have remained one of the most intriguing puzzles of the seasonal forecaster.

Rules 3 and 4 prove that the wave-length is stretched and compressed between two and three years. Evidently the fundamental oscillation would present a period between two and three years in undisturbed conditions. This is in accordance with theory. Finally, we have to answer the question why harmonic analysis emphasizes, as was shown by H. J. de Boer, a mean period of 3·4 years—the same period that was found by H. P. Berlage from tree-ring measurements back over four centuries—although it has no physical reality. There is every reason to assume that the shortest waves lose their individuality in this operation, two crests or depressions coming in very quick succession simply being counted as one. Different facts thus lead to one point of view. The above rules of interaction are so simple that we may hope to be able even before long to interpret them together by some physical principle of interaction between earth and sun.

Discussion

At the conclusion of the paper an interesting discussion followed, one of the chief contributors being Mr. C. H. B. Priestley, who remarked that Dr. Berlage was the first one to have given a physical explanation invoking the time-lag between air-pressure and sea-temperature fluctuations for the existence of the three-year southern oscillation.

In answer to a question by Mr. MacKenzie about the periodic deviations of the Humbolt current from the Peruvian coast, Dr. Berlage expressed the view that the seven-year period simply resulted from a doubling of the more fundamental 3·4-year period.

In reply to a question by Dr. Andrew Thomson, Dr. Berlage said that there were very few observations of sea temperature along a line from Chile to Indonesia, so that a check on the theory could not in this case be obtained.

Mr. Simpson questioned the explanation of the time-lag given by Dr. Berlage and asked whether it could not be the effect of local sea-water circulations.

In reply to a question by Mr. Hutchings, Dr. Berlage said that the fluctuations of temperature were of the right order of magnitude to account for the changes of pressure, but no calculations had been made as to the precise amount.

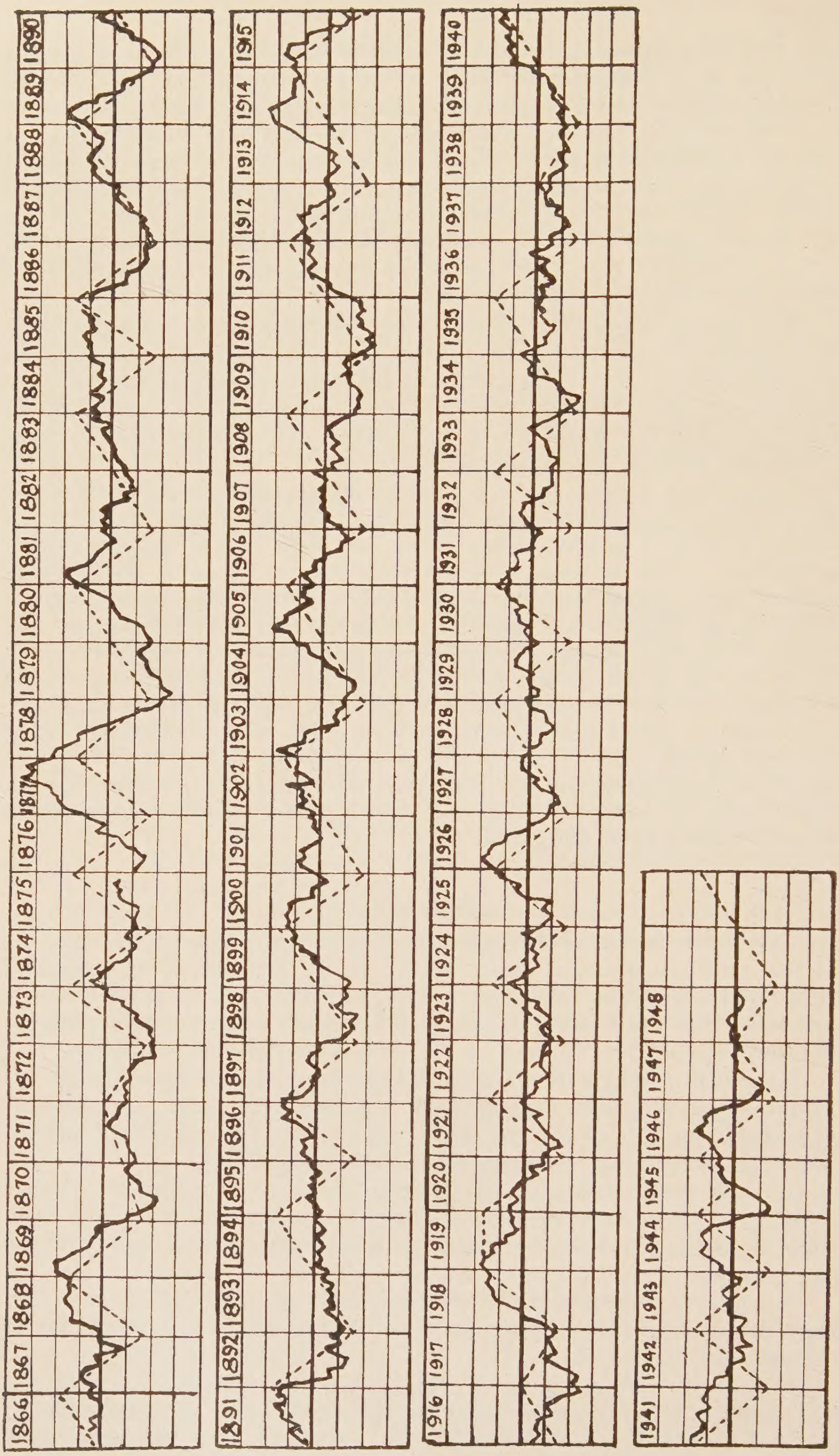


FIG. I.—Six-monthly overlapping means of the deviations from the normal monthly means of air-pressure at Batavia. The dotted curve is a theoretical one derived from the annual sunspot numbers according to the rules mentioned in this paper.

AERIAL WEATHER RECONNAISSANCE IN THE PACIFIC

By Major William S. Barney, U.S. Air Force

Aerial weather reconnaissance is a relatively new method of gathering meteorological data. The need for aerial reconnaissance became apparent during World War II when many areas were cut off from the normal exchange of weather information. In the latter years of the war great loss of lives and military property occurred due to the lack of proper information concerning existing weather conditions. In addition to the loss of information from areas occupied by enemy forces, the Pacific theatre of operations recognized the need for aerial reconnaissance due to the sparse network of land and surface vessel reporting stations.

To meet the military requirements for additional weather data the Allied Powers resorted to aerial reconnaissance. This was necessary to ensure successful air operations, landing operations, and security of naval warships and Army and Navy transports. As the war progressed, aerial reconnaissance gradually improved, and, through the lessons learned in the first few years, aerial reconnaissance has now been developed into a dependable and scientific method of obtaining weather data.

In an attempt to fill in the gap between the land stations, weather ship reports and in-flight aerial weather reports from both commercial and military aircraft, the Air Weather Service of the United States Air Force has established a system of aerial reconnaissance flights emanating from Guam, Marianas Islands, and which covers the south-western and western and north Pacific areas. I will go into detail on these special flights a little later on in my discussion. One of the main reasons for aerial reconnaissance in the Pacific is to locate and investigate typhoons. The relatively few land weather stations in comparison with the immense water areas surrounding them permits the development of strong typhoons before a land station is aware of their formation, and the further lack of an extensive network of reports makes their location and their movement uncertain. Aerial weather reconnaissance is the most expensive method of gathering weather information ; however, it is felt that aerial weather reports will enable forecasters to make more accurate predictions on the formation, intensification, and movement of tropical disturbances and typhoons and will increase the safety factor for ships at sea, land installations, and commercial carriers. The cost of aerial reconnaissance pays for itself in the saving of lives and property, both stationary and mobile.

To obtain the best possible aerial weather observations a great deal of time, thought, and money has been put into the problem. First of all, aircraft to be used had to be selected for their range, altitude, crew comfort, speed, and economy. During the war economy was not a major factor ; therefore aircraft utilized were generally the bombardment and fighter type. Due to decrease in aircraft manufacture at the close of World War II aircraft which were to be utilized in aerial reconnaissance were drawn from depots where large stocks of combat aircraft were stored. Therefore to-day we are using B29 superfortresses for weather reconnaissance missions because they have the greatest range of aircraft available for the purpose ; also they are capable of flying the desired altitudes without discomfort or increased fatigue to reconnaissance crews. The B29's now utilized have been modified into a flying weather observation station. This modification consists of installation of a psychrometer, an aerograph, special work table for the observer, and the addition of newer types of radar and radio equipment in the aircraft. These flying observation stations also carry a radar altimeter in addition to standard pressure altimeter. Numerous types of instruments to assist in air navigation are required, as reconnaissance aircraft, when flying fixed track missions, may not deviate from prescribed altitude and course for weather causes. For example, as a computation of winds at various altitudes is an absolute necessity, equipment must be available in the aircraft whereby the navigator may obtain double drift winds when the surface is visible, by Loran when flying in clouds, and by radar when adjacent to chains, atolls, and isolated landmarks and Loran coverage is not available.

Secondly, the weather reconnaissance crew must be a very well-trained team which must function as such in order to ensure rapid and exact observations as well as rapid means of communication to centres where the data may be disseminated as rapidly as possible. Pilots, navigators, radio operators, engineers, and radar operators have all been extensively trained and are among the best in the United States Air Force. General requirements for pilot co-pilot combination calls for a minimum of 2,000 hours in four-engine aircraft. Combat or transport experience is desired. As some tracks flown are over a distance of 3,000 nautical miles where no land or land mark is available, navigators must be extensively trained in dead reckoning, radar navigation, and celestial navigation. In flying at high altitudes where ground speed often approaches or exceeds 300 miles per hour the navigator is required to calculate an exact position, wind direction, and ground speed at the next fixed point as well as track made good every twenty minutes. Flying inside typhoons does not eliminate this requirement.

As reports are frequently relayed to one or more stations every twenty to twenty-five minutes and observations generally include a minimum of fifteen five-digit groups, radio operators must be capable of air-to-ground communication where the rate of communication desired seldom falls below twenty words per minute. The radio operator must be familiar with all air-borne radio equipment as lack of communication with ground stations eliminates any value which observations taken synoptically may have. Also the radio operator must be well trained in procedure and have expert knowledge of all radio networks, both American and foreign, in case alternates are required.

As all missions are flown over water areas during fair and foul weather the proper functioning of aircraft power plants and the utilization of fuel is of paramount importance. For this reason aircraft engineers have been extensively and thoroughly trained so that long missions may be flown with the greatest possible saving in fuel and engine wear and yet obtain maximum cruising speeds.

Radar operators must be thoroughly familiar with all types of scope interpretation, especially that portion which pertains to clouds, precipitation static, and other types of interference. They must be able to guide the aircraft through the centre of tropical depressions and typhoons by interpreting the radar picture they obtain by use of air-borne radar sets. In addition, the radar operator maintains a constant search at all times for extensive or odd types of clouds and atmospheric phenomena as well as any or all air-borne objects, and must be able to inform the weather observer of typhoon quadrants where the greatest precipitation, most intense ground areas, and weakest areas of tropical storms and typhoons are located. In addition, the radar observer must know how to compute ground speeds as well as wind directions and velocities from objects on the surface and, if necessity arises, to compute such wind velocities and directions from clouds when in his area.

Other operational crew members are the two scanners, who are responsible for constant observance of the engines and airframe and who report any deviations from normal such as smoke, sparks, flame, or structural failures.

Another crew member who has recently become important is the dropsonde technician and analyst. To date such a technician has not been utilized extensively in the Pacific due to imperfections in dropsonde manufacture. The dropsonde technician and analyst is responsible for the release of the dropsonde and recording of the elements transmitted. These elements are the same as those transmitted by radiosonde transmitters. Due to increased range caused by the aircraft's motion as well as winds experienced, the technician must be thoroughly trained and capable of high speed operations.

The main position in a weather reconnaissance crew and one not mentioned previously is naturally the aerial weather observer. Current requirements for an aerial weather observer are (1) graduation from a prescribed Air Force meteorological school or from prescribed civilian universities. In addition to graduation from such institutions the aerial weather observer must have served a minimum of one year of forecasting duty for aerial operations. Aerial weather observers are usually commissioned officers or non-commissioned officers of the first two grades. (The equivalent to a master or technical sergeant in the United States Air Force is a chief petty officer or a petty officer first class in the United States Navy or a sergeant-major in air organizations of the British Empire.)

Many hours are spent and many missions flown to mould a group of individuals, each a specialist in his own field, into a well-co-ordinated and well-trained weather reconnaissance crew.

Around the observer's position located in the nose of the aircraft and the position normally occupied by the bombardier in combat aircraft are located flight instruments normally made available to pilot, co-pilot, navigator, and radar observer. Besides special instruments listed in the beginning of the discussion, flight instruments such as air speed indicator, remote indicator for navigator's flux gate compass, pressure altimeter of the Kollsman type, &c., are located. The psychrometer is located overhead and to the right and the aerograph is located forward and to the left. In addition to the instruments listed, a wire recording instrument is made available so that readings of various instruments and voice comments of the aerial weather observer's visual observations may be recorded while the aircraft is flying through areas of intense turbulence and where the interphone must be utilized at all times in maintaining fixed heading, a fixed altitude, proper power settings and reflections of the scanners and aerial engineer.

Now turning to actual reconnaissance procedures, I will describe the various types of weather reconnaissance as employed by the weather reconnaissance squadron on Guam, which is responsible for all Air Force weather reconnaissance in the Western Pacific. I have served with the weather reconnaissance unit on Guam for a period of one year and have flown several missions, both typhoon and fixed track, with all crews of the organization.

The Air Force weather reconnaissance squadron located on Guam is responsible for fixed track reconnaissance, for typhoon discovery and tracking and for other missions relating to weather which the Chief of the Air Weather Service or the Commanding General, Far East Air Forces, may prescribe, either in peace or in war.

Fixed track reconnaissance is the type of reconnaissance most commonly used. This type of reconnaissance gives the greatest possible amount of synoptic information, both at the surface and aloft, and actually furnishes a basis whereby most typhoons or tropical storms are discovered in the Western Pacific. Fixed track missions performed by the weather reconnaissance squadron are known as Vulture tracks.

Weather observations on Vulture tracks are made and transmitted every 100 nautical miles. Observations include time, position, wind, temperature, surface pressure or height of 700 or 500 millibar level, clouds including types and the height of tops and bases, state of sea, present and past weather, &c. A cross-section is made while in flight showing all such information pictorially in addition to the weather log.

Upon return to operating base the observer immediately makes a post-flight summary from observations made in flight and descriptions and positions of areas where he suspects the formation of tropical storms. This post-flight summary is distributed to all sub-centres in the typhoon network and to all stations responsible for forecasts over the areas.

At present the requirement is for three such tracks to be flown daily to the north, south-east, and south-west of Guam.

Throughout the world the United States Air Force maintains four reconnaissance squadrons, which are constantly engaged in obtaining synoptic data from areas where reports were formerly denied. The organization based on Guam is the 514th Reconnaissance Squadron, Very Long Range, Weather. In Bermuda the 373rd Reconnaissance Squadron is located and is responsible for synoptic reports from the Western Atlantic as well as hurricane reconnaissance in that area bounded on the south by the Equator, on the north by the Labrador current, on the east by the Azores, and on the west by the short line of North America. In Fairfield-Suisun, California, the 374th Reconnaissance Squadron is located and is responsible for Stork and Lark flights over the Eastern Pacific Ocean. The 375th Reconnaissance Squadron is located in Alaska and is charged with reconnaissance of the North-east Pacific Ocean by Loon and Albatross flights and for the Ptarmigan flights over the Polar ice cap and the North Pole.

The other types of reconnaissance which the Air Force is responsible for is typhoon reconnaissance. Typhoons are normally discovered from reports made by aircraft flying fixed track from the north, south-east, and south-west of Guam. Indices normally associated with tropical cyclone formation and readily indicated by reconnaissance reports are : change in wind direction, increased swells and whitecaps, cloud types, fall in surface barometric pressure, decrease in the height of the 700 millibar level, &c. As most weather in the tropical Pacific area is generally of the same type from day to day any departure from normal is reported and is generally viewed with apprehension. Close communication with land forecasting stations must be maintained at all times in order that reports may be rapidly evaluated and disseminated to all interested agencies. Within a few minutes after an aerial observation is made the report has been received at the typhoon warning centre or sub-centre.

The designated typhoon warning centre of the Far East Air Forces responsible for typhoon warning in the Pacific area is located at Harmon Air Force Base, Guam, Marianas Islands, and sub-centres are located at Clark Air Force Base, Luzon, Philippine Islands ; Kadena Air Force Base, Okinawa, Ryukyus Islands ; Haneda Air Force Base, Honshu, Japan and Hickam Air Force Base, Oahu, Territory of Hawaii.

The typhoon centre is responsible for the initial detection of tropical storms and for the preparation and distribution of advisories of tropical storms and typhoons, the assignment and transfer of forecast responsibility to various sub-centres, forecasting the position and direction of tropical storms or typhoons and the preparation and distribution of typhoon bulletins to weather stations, and of forecasts to major Army, Navy, Air Force, and civilian agencies.

Throughout this discussion the words " tropical storm " will be used to describe all depressions where the wind velocity is over 27 knots but less than 66 knots. " Typhoon " will be used when winds are over 65 knots.

Once a tropical storm or depression is suspected over any particular area the typhoon centre on Guam analyses all available data and decides whether or not reconnaissance for the following day should be diverted from a fixed track mission to reconnaissance of the suspected tropical storm. Very close contact and co-ordination must exist between the typhoon centre, the reconnaissance squadron and the appropriate naval agencies in order that flight capabilities for the following day may be determined and available aircraft utilized to the fullest extent. If an intense tropical storm is suspected or forecasted, then the availability of aircraft over a period of several days must be considered as the maintenance of aircraft flying long missions at high altitudes is difficult. Therefore, conservation of aircraft in commission must always be considered.

If the typhoon centre decides that typhoon reconnaissance is required for the suspected tropical storm and the unit is capable of such reconnaissance, crews are alerted and the aircraft made ready for flight. Preflight of aircraft, briefing of crews, and other preparations for a long and hazardous flight require from two to three hours ; therefore, extreme care must be exercised to ensure that sufficient daylight hours remain to prepare for flight and then fly to the suspected tropical storm and complete the required reconnaissance. Night reconnaissance has been attempted, and with present equipment has proven not as satisfactory. It has been the policy of the Air Weather Service in the Pacific to obtain two fixes daily on tropical storms. To obtain the most complete information which will better aid in forecasting movement and intensity and to furnish the latest possible information concerning the location of tropical storms, reconnaissance is normally completed in the early daylight hours and the late afternoon. It is not unusual for an aircraft to depart at midnight to complete early morning reconnaissance on a tropical storm ; neither is it unusual for aircraft completing late afternoon reconnaissance to land at midnight or the early morning hours.

The choice of co-ordinates for reconnaissance over the area adjacent to the storm centre will be governed by several factors such as operational limits of the aircraft, hours of daylight remaining, and the position of the tropical storm as related to regularly flown tracks. The typhoon centre or sub-centre requesting reconnaissance will generally request certain areas to be reconnoitred adjacent to the storm centre before flight time. In addition, the typhoon centre or sub-centre planning the mission always requests that the mission be flown at an altitude and by the method which will provide the most useful weather data for their particular need.

Reconnaissance procedures involving tropical disturbances are such that two procedures are actually used, depending on whether investigation of a storm or typhoon is to be made.

In storm or search reconnaissance the flight altitude to the storm area will be made at 1,500 ft. Flight altitude within the storm area is the pilot's choice within feasible operational limits.

Upon entering the circulation of the storm a heading will be maintained that will keep the wind to the left of the aircraft or at an angle of 90° from the wind-flow. If the wind is due west the heading will be north. If due east the heading will be south.

Such a heading will normally take the aircraft to the storm's centre. However, if the centre of the storm is difficult to locate an alternate plan is used. This method is to assume a heading with the wind so as to partially circumnavigate the storm. To do this a heading with the wind is assumed, and this heading maintained until the wind has backed to 40 or 50 degrees from the tail and to the right of the aircraft. Then the aircraft's heading is changed so as to again fly parallel with the wind until the wind again backs 40 or 50 degrees from the tail and to the right. This procedure, if accomplished on from two or four legs, will enable the navigator to fix the centre by triangulation. The aircraft will then proceed to that point and reconnoitre until the centre is definitely established. When this is accomplished a fix will be obtained and a complete observation made. The aircraft will then leave the centre and complete the circumnavigation of the storm. This is usually done at a radius of from 60 to 100 nautical miles of the centre. Circumnavigation will be made through 270 degrees so as to make observations at four points equidistant from the centre and to the north, south, west, and east of the centre. This ensures that all quadrants are covered and gives information needed by the forecaster in predicting rate and direction of movement. It is true that navigation error due to frequent heading changes and rapid wind shifts will make this method difficult at times, but will generally afford the desired information.

After completing the circumnavigation the aircraft proceeds, if operationally practical, to the nearest staging base along the storm's expected track and at an altitude of 1,500 ft. If this is not feasible the aircraft will proceed from the storm in a direction predetermined by the typhoon warning centre and which will give the forecasters the most useful reconnaissance prior to return of the aircraft to the staging base. Flights are so planned as to provide weather data to the limit of the storm's influence.

In reconnaissance where a typhoon is known or suspected to exist the flight altitude to the typhoon area will be made at the 700 millibar level.

Observations will be made every 100 nautical miles to the typhoon area. Within the typhoon, observations will be made every twenty minutes, or at prescribed positions and/or when weather encountered warrants such observation.

Upon entering the area of the typhoon the precedure is the same as for a storm. However, at the 700 millibar level the use of radar, pressure differential, and visual observation of cloud formations, when possible, simplify this procedure.

Upon reaching the centre or the " eye " the weather observer makes a complete observation. Particular care is taken in computing the height of the 700 millibar level. An effort will be made to determine the slope of the centre if a slope exists. From radar scope readings the weakest quadrant is determined, and the aircraft then departs the centre through that weakest quadrant to the radius of 50 or 60 knot winds, where a spiral descent and sounding is made. The typhoon will then be circumnavigated, using the same procedure as in the case of a storm. To better evaluate the equation evolved by Bjerknes and Holmboe the typhoon should be circumnavigated in the area of typhoon force winds. This will vary, of course, but in all events circumnavigation is made as nearly symmetrical as possible. The best radius to utilize is the one which places the track of circumnavigation between the inner ring of cumulonimbus and the outer ring of towering cumulus. The relative intensities of the quadrants is obtained by radar or actual flight and reported to the typhoon centre.

As in fixed track reconnaissance, coded reports are relayed at all times plus such plain language messages as are required to present the proper weather picture. Data transmitted includes temperature, surface winds, maximum surface winds, cloud types and amounts, relative humidity, present weather, past weather, turbulence and any special phenomena observed, such as icing or lightning.

A cross-section is made showing cloud type and amount of weather, turbulence, icing level, wind direction, and force with the observation positions labelled giving position in degrees and tenths.

After return to operating base the observer immediately makes a post-flight summary from information obtained while in flight. Post-flight summaries give a narrative of the weather encountered and a description of the tropical storm or typhoon. Post-flight summaries are given the same dissemination as in-flight typhoon reconnaissance reports, and are extremely valuable to the forecasters who are responsible for typhoon warnings.

It is a common belief that aerial weather reports are of less value than surface reports. This belief not only exists among laymen but also among large groups of trained meteorologists, and it is frequently difficult to dispel their ideas concerning the value of such reports. However, after a season's work in areas where reconnaissance reports are frequently the only ones available, they become adamant about the need for more and more weather reconnaissance reports.

Regardless of this, the fact remains that reconnaissance reports are extremely valuable not only for their timeliness, mobility, and frequency, but because such observations are what may be called three dimensional. To the observer on the surface observations above the lower stratus deck are impossible to take. The surface observer cannot observe the various clouds above such a level, and therefore has little conception of the many cloud decks, their configuration, and their direction of movement. The only method of upper air observations during poor weather are rawin or radiosonde, and these are frequently not usable or incomplete due to high winds limiting the time of observation and other atmospheric phenomena, such as static interference hindering the run.

Most arguments against reconnaissance reports (other than high cost) are that such reports are usually inaccurate. Arguments such as these are a carry over from previous years when aerial navigation was accomplished solely by dead reckoning, celestial and radio means, or a combination of all. By use of long-range navigation (LORAN) it is possible to fix positions within 1 to 5 miles of the actual and with such frequency that other methods are seldom used. In case of LORAN failure, air plot to a fixed position and recomputation will give position to within 20 to 30 miles. Considering the scale of our present synoptic charts, both are negligible as far as practical forecasting is concerned, as the centre or " eye " of a well-developed typhoon will generally have a diameter as large as the maximum navigational error. If the argument is advanced that such error is too great it can be truthfully said that errors arising from triangulation fixes from surface reports are much greater due to the fact that the gradient wind must be ascertained in order to actually obtain a fix from triangulation and also the accuracy of a triangulation fix is directly proportional to the symmetry of the typhoon.

The degree of error in wind computations seldom exceeds 15 degrees and 5 knots, and when multiple drift winds are obtained using modern drift equipment the error is much less. Due to rapidly changing directions and velocities near typhoon centres actual winds are difficult to obtain. Radar fixes are valuable in wind computations as the wind is vectorially computed by use of true airspeeds and headings compared with the fix. However, the degree of accuracy in such computations is directly proportional to the distance between fixes up to the neighbourhood of 100 nautical miles. Some error does exist in such computations, as stated previously, due to the ever-changing directions and velocities found in typhoons, and the error increases with distance. The pressure differential or Bellamy method is fairly accurate in giving cross-wind drift components by comparision with true airspeed, and when ground speed is ascertained by radar fixes will give a fairly reliable wind reading. In all instances, though, when flying at angles to isobars the varying directions and velocities make extremely accurate wind computations difficult. Actually the observation of the ocean's surface gives the best indication of wind velocity as the observer soon learns to associate wind velocity with types of white caps, sea swells, patches of foam, or complete obscurement of the surface by froth. With the centre accurately determined by a LORAN fix the direction of wind near the centre is not too important ; however, knowledge of the velocity is of paramount importance in typhoon warnings, but the fact remains that precautions for an 80-knot wind would be about the same as for one of 90 knots, and if it can be said that the velocity is over 75 or 80 knots, and such observation is correct, the warning service is more than adequate. In storms which have not reached typhoon intensity wind velocities can be computed to the nearest 5 knots as cloud covering is usually such that an increase or decrease in altitude of 100 feet will allow a multiple drift computation.

True altitude, temperature, humidity, and pressure readings are exceptionally accurate as they are scale or scope readings or mathematical derivations of both. Maximum errors are 50 ft. in altitude, one degree Centigrade of temperature, 5 per cent. of relative humidity, and at low levels surface pressure is computed to the nearest millibar.

Accuracy of visual observations of clouds, weather, visibility, and state of sea depends on the observer and are generally more accurate than a surface observation. The aerial observer usually has a better picture of the weather as he can better report the cloud structure, the cloud heights, their thickness, &c.

Entering a typhoon for the first time is an experience few people forget. This is especially true of a well-developed typhoon. Normally you have been flying for from twenty to thirty minutes on instruments with the sound of heavy rain beating against the fuselage almost eliminating the noise of the motors. Suddenly the aircraft breaks through the heavy dark clouds into the clear, similar to stepping from a dark cellar into midday. The sun will be shining, usually through a thin veil of cirrus or high alto stratus. My first experience in entering the centre of a typhoon was just at sundown. The effect was rather startling. We were suddenly confronted by the most weird sight we had ever seen. There was every type of cloud imaginable present, and all were moving in different directions. The sun's rays reflected from higher clouds and downward from layer to layer gave every colour of the spectrum. Rainbows were everywhere. The centre was between 15 to 20 miles in diameter, perfectly cylindrical in shape. Not even scud clouds marred the centre. The sea surface was calm, but beneath the base of low clouds surrounding the " eye " the sea suddenly became a mass of froth. On first sight the impression was that we were flying over a lagoon which was protected from a rough and angry sea by some circular barrier. Ahead of us we could see the lower clouds rotating to the left with foam and spray an estimated 60 ft. in the air. To the right and left of the aircraft the clouds were moving in divergent directions, and the surface had the same characteristics as the surface ahead. We crossed the eye towards the east, encountered a few seconds of moderate turbulence, when we again entered the wall of clouds, and everything again became dark. After flying through the cloud wall and obtaining a double drift we assumed a reciprocal course, and in approximately thirty minutes again broke into the centre. As the heading was almost due west into the sun the appearance of the clouds was even more awesome. The only difference was that the centre had been displaced some ten miles north-north-west of its original position. The same sudden jar was again experienced as we entered the cloud wall to the west.

Weather instruments on weather reconnaissance aircraft have heretofore been covered rather hurriedly. However, much research and time has been consumed in construction of instruments in order to meet the rigid requirements for such instruments.

The four important instruments currently installed are the psychrometer, aerograph, radio altimeter, and radar set.

The ML-313AM psychrometer is an accurate instrument for measuring temperature and relative humidity. The temperature-lag for this instrument is negligible compared to the lag experienced on the standard aircraft thermometer. The ventilator is 18 in. long and 3 in. in diameter, and is installed 4 in. from the outside surface of the fuselage.

The pioneer type aerograph AN/AMQ-2 was especially designed for reconnaissance work and is used to obtain a continuous record of pressure, temperature, and humidity in the atmosphere and the airspeed of the aircraft.

This instrument has four major parts, a pressure-air-speed transmitter, temperature-humidity transmitter, temperature-humidity ventilator, and the recorder.

(*a*) The pressure-air-speed transmitter measures the pressure of the atmosphere and the air-speed of the airplane, and transmits these values to the recorder. The pressure unit is connected to the static line, and the airspeed unit is connected to both the static and pitot lines.

(*b*) The temperature-humidity transmitter continuously measures the temperature and relative humidity of the atmosphere and transmits these values to the recorder. The transmitter consists of two transmitting units, one actuated by a bi-metal thermometer and the other by a hair hygrometer.

(*c*) The temperature-humidity transmitter is installed in a ventilator mounted outside the plane to the left and rear of the pilot's position. The ventilator is approximately 18 in. long and 2½ in. in diameter.

(*d*) The transmitters are electrically connected to the aerograph recorder which makes a continuous record of all functions in four colours, printing once a second on a 100-hour chart roll. This recorder is located to the left of the bombardier's position.

The radio altimeter, SCR-718, is mounted to the left of the bombardier's position and is adjacent to the pressure altimeter to afford rapid comparisons.

The radar set AN/APQ-13, modified to include an A-scope indicator and a longer pulse length, is used on weather reconnaissance aircraft. With this set the beam scans 360 degrees, as compared with only a 60-degree angle to the front on standard models.

Another instrument now being perfected is a cloud scope for measuring the base and tops of clouds and will probably be installed in the near future.

After all typhoon or storm reconnaissance missions, and in addition to the post-flight summaries, all crew members give a post-flight narrative of the flight with particular emphasis on their position. These narratives are used in making changes in procedures, instruments, and also are extremely valuable for typhoon analysis, and research as many points are covered that the observer fails to record while flying in severe weather conditions.

Following is an aircraft commanders post-flight report of the ninth mission flown reconnoitering Typhoon Beverly. The date was 7th December, 1948. The aircraft commander was First Lieutenant David W. Lykins, United States Air Force. I quote :—

AIRCRAFT COMMANDER'S REPORT

Vulture " Beverly " IX
7 December 1948
Aircraft No. 6450

Crew A-1 was briefed at 1000Z, 7 December 1948, to fly tropical storm " Beverly," fix number nine, using a new method of reconnoitering the storm area.

The operations office instructed us to climb to the 700 millibar level after take-off, penetrate the " eye " of the storm, take a fix in the centre, then make a spiral descent and sounding down to 1,500 ft. and proceed out of the storm on a north-westerly heading to begin the pattern around the storm centre. The pattern consisted of four legs forming a square around the centre, each leg being seventy miles long and oriented north, south, east, and west. In flying the legs the movement of the storm was to be taken into consideration as the pattern progressed, to keep the legs approximately 60 miles from the centre.

It was believed that information determined from this pattern would aid in more accurate forecasting of the movement of the storm.

After the briefing the crew ate dinner and returned to the aircraft to load personal equipment.

At 0300Z I had received my ATC clearance from North tower and I started the take-off run.

When I was airborne with the gear and flaps up I made my initial contact with Guam control. There was no reported traffic so we were cleared from control. The instructions were complied with and a heading of 270 degrees was taken up.

At approximately 0500Z there was discernible on the horizon a vast coverage of cirrostratus at about 30,000 ft. This indicated to us the presence of the storm, verified by the south wind and slight swells that were perpendicular to our flight direction.

The wind was increasing and the swells were noticed to intensify. The boundary of the storm area was very distinct as we approached the edge. At this point the surface wind was estimated to be 35 knots from 180 degrees.

At 0738Z the surface wind was observed to have increased to 45 knots, and light turbulence was encountered.

At 0742Z moderate turbulence was experienced and a stratacumulus ring of clouds was observed extending in a north-south direction for a distance of about 100 miles. Scattered lightning was detected. An undercast of approximately 7–9/10 stratacumulus was below us and the surface wind was observed to have increased to 60 knots. The outside air temperature remained 10 degrees centigrade, the same as before entering.

Moderate rain was encountered at 0756Z, the surface wind increased to 70 knots and moderate turbulence was encountered.

From this point on we were on 100 per cent. instrument flying conditions and the moderate to heavy rain and moderate turbulence persisted until we missed the " eye " and flew south for fifteen or twenty minutes.

Because we were on instruments and could not see the surface we could not determine the highest wind velocity in the storm. It is estimated close to 100 knots.

As we went on instrument conditions we noticed that we had a good drift correction for hitting the centre satisfactorily, so we held the 270 degree heading relying on the radar observer to be able to see the " eye " on the scope. The radar had been functioning satisfactorily, and we had a very competent radar observer operating the set.

Approximately fifteen or twenty minutes later the radar observer reported seeing a semi-circular ring of clouds about 25 degrees to the right at about 25 miles range. The same ring was detected to the left about the same distance. Figuring we had drifted to the right of the centre we elected to intercept the left return.

We flew until we received a definite pressure rise and decided we had made a wrong choice.

To make sure that we weren't chasing circular rings of heavy clouds on the scope we made a turn to 180 degrees and held it long enough to enable us to see the surface wind. After about ten minutes we saw the surface and saw the wind to be coming from approximately west-north-west. We then headed back for the centre of the storm with the wind off our left wing, allowing 15 to 20 degrees for drift.

In approximately fifteen minutes the radar observer reported the " eye " as being almost directly ahead.

At 0906Z we broke out into the most beautiful and well defined " eye " that I have ever seen. It was a perfect circle about 30 miles in diameter and perfectly clear overhead. The sides sloped gently inward toward the bottom from 25,000 ft. and appeared to be formed by a solid stratus layer down to approximately 5,000 ft. From 1,000 ft. to 5,000 ft. were tiers of circular cumulus clouds giving the effect of seats in a huge stadium.

The wind was estimated at about 35 knots in the centre. No calm water was seen because of the under-cast.

After the navigator had taken a LORAN fix, and the weather observer had taken his observation a sounding was begun to 1,500 ft., using the " eye " as the let-down area.

When we reached 4,100 ft. indicated altitude, using the pilot's pressure altimeter, the weather observer informed me that our actual altitude was 1,500 ft. by the radio altimeter.

At this point we leveled off and took up a heading of 305 degrees to leave the " eye " through the quadrant that appeared to be the weakest on the radar scope.

Before entering the wall of weather surrounding the " eye " we turned on all the cockpit lights to avoid being blinded by the lightning that had been observed while in the " eye."

As we entered the edge of the " eye " we were shaken by turbulence so severe that it took both pilots to keep the airplane in an upright altitude. At times the updrafts and downdrafts were so severe that I was forced down in my seat so hard that I could not lift my head and I could not see the instruments. Other times I was thrown against my safety belt so hard that my arms and legs were of no use momentarily, and I was unable to exert pressure on the controls. All I could do was use the artificial horizon momentarily until I could see and intercept the rest of the instruments. These violent forces were not of long duration fortunately, for had they been, it would have been physically impossible to control the airplane.

Since the updrafts and downdrafts were so severe and we were unable to maintain control of the altitude all we could do was to hold the airspeed within limits to keep the airplane from tearing up from too much speed or from stalling out from too little. After the first few seconds we managed to have the third pilot, who was riding on the flight deck, advance the R.P.M. to 2,400 so we could use extra power in the downdrafts and start a gradual ascent from the area. Neither of us at the controls dared leave them long enough to do it ourselves.

The third pilot received a lump on his forehead when he struck the rear of the pilot's seat, and bruised his shoulder from another source in doing so. Since he had no safety belt he was thrown all over the flight deck.

This area of severe turbulence lasted between five and six minutes, and every second during this time it was all both of us could do to keep the airplane at a safe altitude, keep it within safe airspeed limits, and maintain a general heading.

It is almost impossible for me to describe accurately or to exaggerate the severity of the turbulence we encountered. To some it may sound exaggerated and utterly fantastic, but to me it was a fight for life.

I have flown many weather missions in my thirty months in the 514th Reconnaissance Squadron, I have flown night combat missions in rough winter weather out of England, and I have instructed instrument flying in the States, but never have I even dreamed of such turbulence as we encountered in typhoon " Beverly." It is amazing to me that our ship held together as it did.

When the severest turbulence subsided we found we had gained an altitude of about 6,000 ft. At this point we decided to climb to 10,500 ft. and proceed directly to Clark Field. It was night time, and since we were shaken up pretty badly this was the most sensible course of action to be taken because we had no way of knowing the extent of any damage we might have sustained.

The engineer reported that the booster pumps had all gone into high boost and one generator had failed. The radar observer said that the rear of the airplane was a mess of rubble from upturned floorboards, personal equipment, sustenance kits, &c. The flight deck had extra equipment all over it. In addition, the co-pilot had twisted off a fluorescent light rheostat switch when we hit the turbulence as he was adjusting it. The radar observer reported his camera had fallen to the floor.

During the climb the scanners checked the exterior of the ship with Aldis lamps to ascertain any damage sustained. Control cables the length of the fuselage were also checked for obstructions. Everything was found to be in order, except for the afore-mentioned heap of loose equipment.

We made contact with Clark Field tower about 80 miles from Clark Field after trying vainly to raise Manila Control. Clark tower cleared us to Clark Field at our cruising altitude, and then Manila control gave us a call verifying Clark tower's instructions.

Clark Field was V.F.R. with an unlimited ceiling. We made a spiral descent VFR and landed at 1135Z, concluding 8 hours and 35 minutes of flying time. We logged two hours of day weather time, and one hour and twenty-five minutes of night time, and two hours of night weather time.

After my experience in leaving the " eye " of " Beverly " at 1,500 ft. the undersigned has only one statement to make and it cannot be overemphasized.

An airplane with human beings aboard should never be required to fly through the " eye " of a typhoon at an altitude below 10,000 ft. If a pattern must be flown at 1,500 ft. in the storm area it should be clearly indicated that the area of the " eye " be left at the 700 millibar level and the descent be made at a distance of not less than 70 miles from the centre.

Full use of radar equipment should be exercised in avoiding any doubtful areas.

FISH & WILDLIFE SERVICE
PACIFIC OCEANIC FISHERY
INVESTIGATIONS

As this report is being written the extent of the damage to the aircraft is still being determined. So far the following damage has been found : a slightly bent vertical fin, slightly warped flaps, tears in fairing joining the wing and fuselage, untold snapped rivets on all parts of the airplane, fuselage apparently twisted around the CFC compartment, and the RF unit in the centre section of the bomb bay was torn from its mountings.

A very detailed inspection is being made to determine the full extent of damage.

DAVID W. LYKINS, 1st Lt., U.S.A.F.,
Aircraft Commander.

A certified true copy : William S. Barney, Major, U.S.A.F.

Discussion

In answer to a question by Captain Brownjohn, Major Barney said that vertical ascending currents of up to 5,000 ft. per minute had been observed in turbulent areas of some typhoons.

In answer to a question by Mr. Hutchings, Major Barney replied that warm and cold fronts did not play much part in the actual formation of a typhoon, but did appear later in the development.

Temperature soundings in the eye of a typhoon appeared to give higher temperatures than in the surrounding areas.

Mr. Simpson presented an interesting observation that often the cirrostratus cloud above a typhoon rises as the centre approaches, but no explanation was offered of this.

Dr. Spilhaus observed that very near the Equator typhoons had been noted to rotate in the wrong direction for the hemisphere concerned. Major Barney agreed that this was also the case in his experience in the North Pacific.

The question of thunder and lightning in typhoons was raised by Mr. Hutchings, and Major Barney replied that although thunder and lightning occured frequently, typhoons exhibited surprising changes in the character and intensity of the accompanying electrical phenomena, often in a very short time. Not much was known about these changes.

HURRICANES ON THE WEST COAST OF MEXICO

By Ronald L. Ives, Indiana University

Abstract

Frequency, behaviour, magnitude, and trajectory of Mexican west-coast hurricanes is here outlined, on the basis of information available up to 1948 ; the known and suspected effects of these hurricanes are discussed ; and the need for further study of these disturbances, both along their trajectories and in areas extending many miles beyond them, is noted.

Introduction

Tropical cyclones have been reported from most tropical and subtropical sea areas, and from the lands immediately adjacent to them. Detailed studies of those in the Bay of Bengal(1), the Australian coastal areas(2), the China Coast(3), and the eastern Caribbean Sea(4) are numerous, extensive, and, on the whole, quite dependable except for obsolescence.

In contrast, tropical cyclones on the west coast of Mexico are mentioned only in the more detailed climatic and meteorological works(5), and, even in these, mention is usually brief and unsatisfactory, due in large part to lack of information.

During the last four decades, as a result of careful studies by the Servicio Meteorologico Mexicano, our knowledge of these west-coast hurricanes has been considerably augmented. Within the last fifteen years, as the smaller coastwise vessels have been equipped for radio communication, and the settlements on the Sonoran coast and in peninsular California have been linked to central Mexico by wire and radio, the number of reports of hurricanes, locally known as *cordonazos*, *franciscos*, or *chubascos*(1), has more than tripled, so that the Mexican Meteorological Service is now able to plot the trajectories of some major hurricanes in the eastern Pacific with gratifying accuracy. A sample chart, showing trajectories of tropical cyclones in this area during the year 1936, substantially as plotted by the Servicio Meteorologico Mexicano, comprises Fig. 1.

HISTORY

Probably the earliest records of Mexican west-coast hurricanes are those to be inferred from the non-arrival of the annual Manila Galleon(6); and from the fragmentary reports of " tempestades " to be found in the " Documentos Para La Historia De Mexico(7) ". One such description, written in 1730, probably by Cristobal de Cañas, missionary at Arispe, Sonora, indicates that hurricane behaviour was known, and at least partly understood, prior to that year(8).

Later findings, ably summarized by Hurd(9), show a definite increase in the number of hurricanes reported as the amount of sea travel in the eastern Pacific increased, so that during the past four decades an average of slightly more than six hurricanes has been reported annually. The present hurricane reporting situation, although much improved over even ten years ago, is still far from satisfactory, and has been ably summarized by Hurd " the ' accidental ' encounter of a ship with a violent tropical cyclone in these waters continues, for scarcely a year passes in which some storm owes the only record of its existence to the passage of a single vessel across its path."

If and when the radar tracking procedures, now used in the Caribbean, are expanded to cover also the Mexican coastal waters, this shortage of information will be rectified.

FREQUENCY OF TROPICAL CYCLONES

Temporal distribution of tropical cyclones in Mexican west-coast waters is still problematical, for the aforementioned lack of data makes any estimate subject to a large possible error. By adaptation of the physicists' " mean free path " computations, it appears that about fourteen such disturbances occur in an average year, there being a possible error of plus or minus two in this figure.

---

(1) These terms, the first two of which are local variants of " El Cordonazo de San Francisco " (the lash of St. Francis), are applied to almost any violent windstorm, whether it is a true hurricane or merely a violent local squall. The term *hurricane*, variously pronounced, is also employed in the same general sense; and the term *ciclon tropical* (tropical cyclone) is commonly used by Mexican meteorologists. There are also a multitude of local terms, derived in part from American Indian languages, by which hurricanes are designated. (*Hurricane* is probably derived from one of the Carib dialects, its original meaning being *evil spirit*, or *bad medicine*.) The term *typhoon* is heard occasionally in some areas near the Gulf of California, it apparently having been learned from Japanese fishermen.

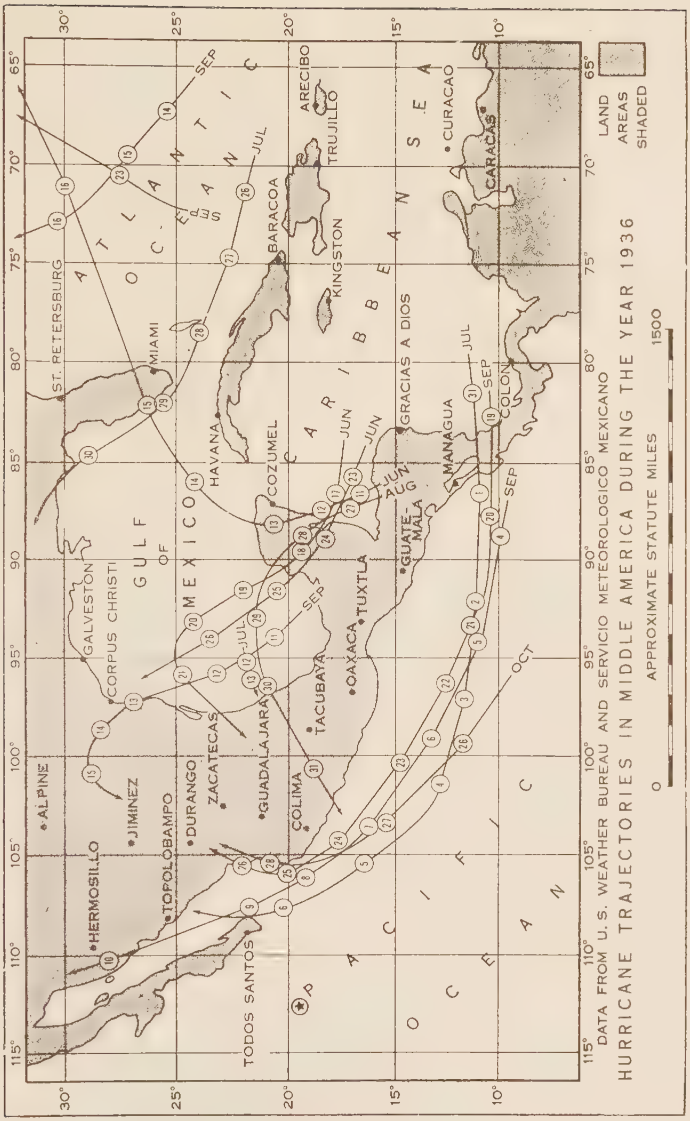

HURRICANE TRAJECTORIES IN MIDDLE AMERICA DURING THE YEAR 1936
DATA FROM U. S. WEATHER BUREAU AND SERVICIO METEOROLOGICO MEXICANO
APPROXIMATE STATUTE MILES
0
1500
LAND AREAS SHADED
ATLANTIC OCEAN
GULF OF MEXICO
CARIBBEAN SEA
PACIFIC OCEAN
ST. PETERSBURG
MIAMI
HAVANA
COZUMEL
BARACOA
KINGSTON
TRUJILLO
ARECIBO
CURACAO
CARACAS
GRACIAS A DIOS
MANAGUA
COLON
GUATEMALA
TUXTLA
OAXACA
TACUBAYA
COLIMA
GUADALAJARA
ZACATECAS
DURANGO
TOPOLOBAMPO
HERMOSILLO
JIMINEZ
ALPINE
GALVESTON
CORPUS CHRISTI
TODOS SANTOS
JUN
JUL
AUG
SEP
OCT
30°
25°
20°
15°
10°
65°
70°
75°
80°
85°
90°
95°
100°
105°
110°
115°

Fig. 1.—Hurricane trajectories in Middle America during the year 1936, as plotted by the Servicio Meteorologico Mexicano. Circled numbers indicate the noon position of the hurricane on the indicated date. Months are indicated at the beginning of the trajectory.

From the cumulated record, consisting of Hurd's summary, augmented by information supplied the writer by the Servicio Meteorologico Mexicano, the percentage distribution of these cyclones, by months, can be plotted. This is shown in Fig. 2 (left). It will be apparent that this distribution is a bipeaked phenomenon, with one (minor) maximum in June, and a second (greater) maximum in September. The September maximum coincides temporally with the rainfall maximum for this area, as is indicated by the climatic chart for Isla Maria Madre (lat. 21° 36′ N.; long. 106° 34′ W—Fig. 2, centre).

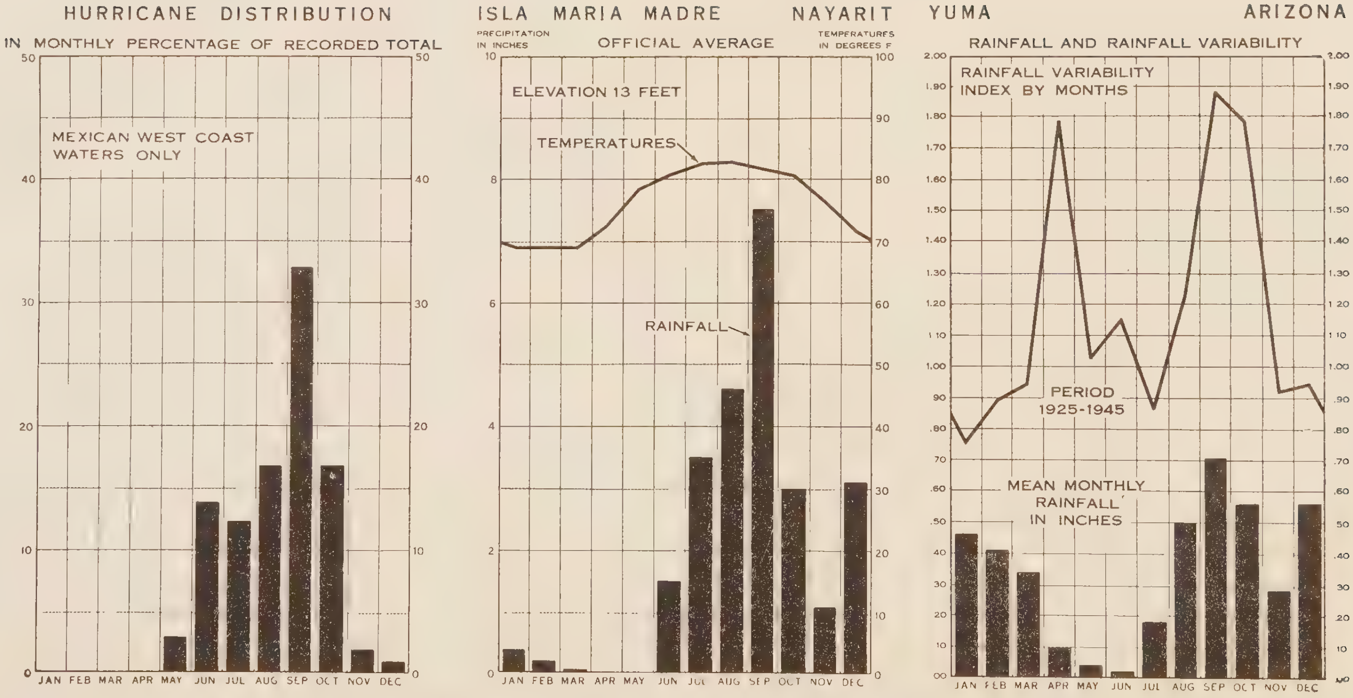


FIG. 2.—Relation of hurricane distribution to weather and climate of adjacent areas. *Left :* Percentage distribution of hurricanes, by months. *Centre :* Climatic chart for Isla Maria Madre. *Right :* Rainfall and rainfall variability at Yuma, Arizona.

HURRICANE TRAJECTORIES

From the accumulated records it appears that a large number, and probably a majority, of Mexican west-coast hurricanes are first reported from the eastern Pacific at about lat. 15° N.; long. 100° W. Backward extrapolation of their trajectories suggests quite strongly that they have a common area of origin somewhere in or near the Gulf of Darien, an arm of the Caribbean between Panama and Colombia.

Study of a number of these trajectories shows that these storms, near their suspected area of origin, are usually relatively small cyclonic disturbances, which do not become full-fledged tropical cyclones until they have travelled for some distance. A few of the disturbances cross the Isthmus of Panama, usually as strong to violent families of squalls; more travel northward, on the Caribbean side of the isthmus, gaining violence *en route*, and cross to the Pacific via the Rio San Juan-Lake Nicaragua gap. In this area they are usually, but not invariably, recorded as strong cyclones, but with winds still considerably below hurricane force.

It is usually not until these cyclones have travelled for several hundred miles over the Pacific that they acquire maximum violence and true hurricane characteristics.

Although a few of these tropical cyclones acquire trajectories in the general direction of Clipperton Island (lat. 10° 17′ N.; long. 109° 13′ W., approximately), and a few others appear to originate in that vicinity, most of these storms travel roughly parallel to the west coast of Mexico, a few hundred miles off shore, from about long. 100° W. (south of Acapulco) to about lat. 20° N. (west of Cabo Corrientes), few reported hurricanes going far west of the Revilla Gigedo Islands (1).

After passing the Tres Marias Islands (lat. 21° 19′ N.; long. 106° 18′ W., approximately), usually to the west, many of the hurricanes recurve, and run ashore on the mainland of Mexico, in the States of Sinaloa or Sonora. A few proceed up the Gulf of California to the mouth of the Colorado River, and enter the United States near Yuma (about 60 miles up the Colorado River, in lat. 32° 46′ N.; long. 114° 38′ W.), at the junction of the Gila and Colorado Rivers, in Arizona.

Other hurricanes continue farther northwestward, eventually contacting the west coasts of Baja California (Mexico) or of (Alta) California (U.S.A.).

About one-third of the reported tropical cyclones in this area are lost at sea somewhere between latitudes 20° N. and 40° N., little or nothing being known of their trajectories north of the Revilla Gigedo Islands.

TRAJECTORY CONTROLS

Hurricanes, according to current theories, which are now regarded as somewhat incomplete, but which contain substantial elements of correctness, are vortical atmospheric disturbances, maintained by the continuing release of the heat of vaporization of the atmospheric moisture carried aloft and condensed to liquid water. In accord with this generalization, and with most rational modifications thereof, a hurricane (or similar disturbance), once started, will continue to exist as long as sufficient water vapour is available (unless it is disrupted by a superior mechanical disturbance) ; the intensity of the hurricane being an approximate function of the specific humidity of the available air.

---

(1) A cluster of uninhabited volcanic islands, surrounded by coral and numerous "obstructions to navigation," at about lat. 18° 50′ N.; long. 112° 40′ W. The largest island, Isla Socorro, is a coffin-shaped mass of volcanic material (Pliocene ?) about eight by twenty-four miles, with a maximum height of about 4,000 ft. The entire group rises from a subsea platform, probably about 250 ft. below the present sea surface.

Because a tropical cyclone, both theoretically and actually, " mines out " the water vapour in a given area in a relatively short time, and, by shading the same area, effectively inhibits evaporation there, a stationary tropical cyclone, lasting for more than a few hours, is not only practically unheard of, but is physically improbable under conditions normally found in Nature. In consequence, a lasting tropical cyclone, or hurricane, must have a trajectory.

Any object on earth, once started in motion parallel to the surface, will tend to pursue a great circle trajectory unless and until it is acted upon by other forces. Because of the rotation of the earth, any object moving away from the Equator, and parallel to the surface, is deflected eastward. This effect of terrestrial rotation, commonly described as the " deflecting force " or " Coriolis Force," increases in magnitude, for a given latitudinal motion, as the latitude increases. In the area under consideration this " deflecting force " becomes more important northward.

Partially opposing this deflecting force are the trade winds, which blow from north-east to south-west (in the Northern Hemisphere) between the Horse Latitudes and the Doldrums, and have maximum intensity, during the time of hurricane maximum, in the area concerned, between latitudes 15° N. and 20° N., becoming definitely weaker and less constant as the subtropical belt of atmospheric subsidence (the Horse Latitudes, about 30° N.) is approached.

Computation of hypothetical hurricane trajectories, considering only the deflecting force due to terrestrial rotation and the effects of the north-east trade winds, shows clearly that a recurved trajectory, starting toward the north-west, and terminating in a north-easterly tangent, is to be expected. Such hurricane trajectories are standard in this area (Fig. 1).

Theory and observations are in such close accord for the first part of most hurricane trajectories that influences other than the trade winds and terrestrial rotation are of minor magnitude here. However, neither terrestrial rotation nor trade wind influence will explain the sharp landward kinking of many hurricane trajectories, nor will they account for the apparent sudden dissipation of other hurricanes at sea, usually north-west of the Revilla Gigedo Islands.

Reference to the pattern of winds, pressures, and ocean currents over and in the north-eastern Pacific during the late spring, summer, and early fall discloses that conditions north-west of Todos Santos (Fig. 3) become increasingly unfavourable to hurricane travel in that direction. A hurricane travelling far offshore in this area encounters opposing winds, which are usually relatively dry, and tend to be or become convectionally stable from contact with a cool sea. In consequence, not only is hurricane travel north-westward opposed mechanically, but the amount of water vapour available for condensation decreases markedly north-westward.

Hurricanes travelling close to shore encounter the cold California current not far north of lat. 25°, and here, almost literally, they " run out of steam " and dissipate.

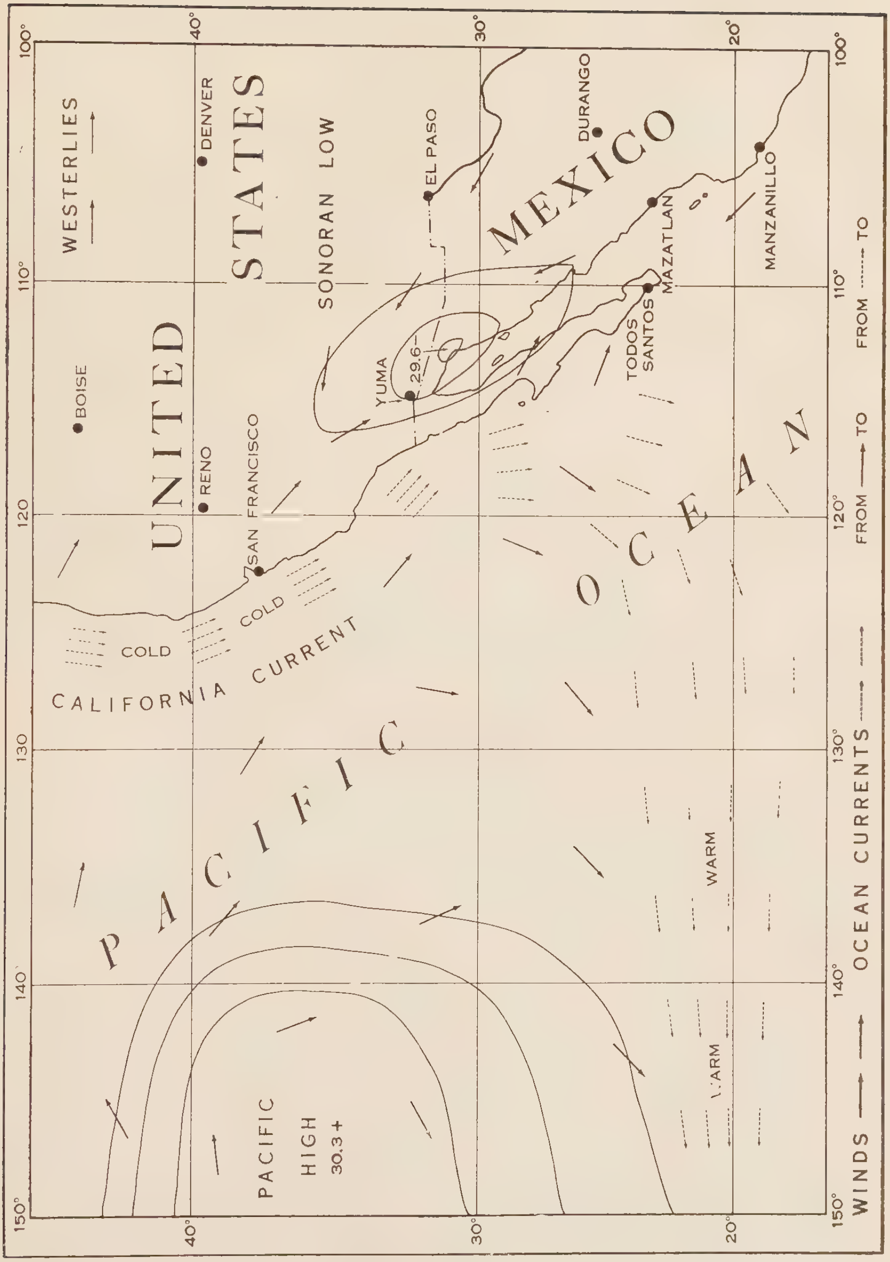

WESTERLIES
DENVER
BOISE
RENO
SAN FRANCISCO
UNITED STATES
SONORAN LOW
EL PASO
DURANGO
MEXICO
YUMA
29.6
TODOS SANTOS
MAZATLAN
MANZANILLO
COLD
COLD
CALIFORNIA CURRENT
PACIFIC OCEAN
WARM
WARM
PACIFIC HIGH 30.3+
100°
110°
120
130
140
150°
40°
30°
20°
WINDS FROM → TO
OCEAN CURRENTS FROM → TO

FIG. 3.—Generalized map showing winds, ocean currents, and pressure pattern in the north-eastern Pacific area during the warmer half of the year.

Because of the prevailing wind pattern in this area, the result of the semi-permanent high over the Pacific, and of the thermal low over the Sonoran Desert region, the deflecting force due to terrestrial rotation north of about 25° lat. is augmented by the winds, so that many tropical cyclones are deflected ashore here.

Hurricanes, and similar disturbances, which travel directly up the Gulf of California usually, but not invariably, vanish within the Sonoran Low (Fig. 3), playing out in that area as a series of violent squalls, producing excessive localized rainfall.

In consequence of the wind and current pattern at sea, most hurricanes in this area either dissipate, or are driven inland, south of latitude 30° N., and none have travelled as far north as 35° during the last half-century. This is in marked contrast to conditions in the eastern part of the United States, where hurricanes not infrequently travel, with strength practically unabated, at least as far north as Boston, in latitude 42° 22′ N. On the eastern coast of North America the Gulf Stream causes a northward extension of the environment favourable to hurricanes for a distance of more than 500 miles relative to that on the west coast.

HURRICANES ON LAND

Most hurricanes which run ashore from Pacific waters on to the lands of North America either dissipate, or undergo extensive modifications, within a distance of from 25 to 300 miles.

A typical west-coast hurricane, on running ashore, produces violent wind squalls, accompanied by intense rainfall, over a small area only. Winds strong enough to carry away the instruments, and to twist radio towers into pretzel-like shapes, are common under such conditions, and rainfalls of as much as 5 ins. in two and a half hours have been recorded. The area affected, however, is usually small, having a diameter of less than 50 miles near the sea, and usually of less than 10 miles 50 miles inland. Because of the aridity and barrenness of much of this area, even a minor hurricane produces serious local floods(10).

Near the head of the Gulf of California many small tropical cyclones are preceded by desiccating fallwinds on the east side of the Peninsular Ranges (Sierra de San Pedro Martyr, Sierra de la Giganta, &c.), in which enormous dust-devils, or miniature tornados, are not uncommon. These minor vortices, on passing from land to water, commonly change to waterspouts.

After travelling for some to many miles over land, tropical cyclones normally diminish in size and intensity, so that they are not easily recognized as hurricane residuals. In many instances they break up into several vortical disturbances, which follow terrain-determined trajectories, usually valleys for many miles.

In some instances these hurricane residuals have been traced as small cyclones or as families of squalls, for more than 1,000 miles. In general, but not invariably, the limit of travel of these disturbances is the boundary of the air mass, usually unmodified or slightly modified Tropical Maritime air, first entered by the hurricane. When these disturbances reach a front, they " ride " up the frontal slope, producing local " cloudbursts." Some of the cloudbursts recorded from such distant points as El Paso, Texas, and Salt Lake City, Utah, are apparently caused by hurricane residuals.

It has been suggested that many of the "extra tropical" cyclones following a southerly path from near the head of the Gulf of California eastward toward the lower Mississippi Valley are actually hurricane residuals, reduced in intensity by long travel over land.

DESIRABLE RESEARCH

Present knowledge permits a qualitative description of the hurricanes of the area just west of the Mexican mainland, but does not furnish the specific quantitative information necessary for accurate tracking or forecasting of these Pacific hurricanes. The need for additional data is known to the weather services of both the United States and Mexico, and extensions of the services are now under way in both countries. International co-operation, which has been excellent for several decades, is now so good that both services function as a single unit during times of emergency.

Detailed study of the played-out remnants of these hurricanes, to determine their effects many miles from the supposed "point of extinction," appears desirable. Present knowledge, which leaves much to be desired, suggests, but does not prove conclusively, that many of the unpredicted squalls which cause so much damage in the western United States are either hurricane residuals or are caused by these residuals acting either as a "trigger," or "last straw," on pre-existing instability, usually in Tropical Maritime air which has invaded the region between the Rocky Mountains and the California Sierras.

Because of the sparsity of population in many parts of the region concerned use of automatic, unattended weather stations, reporting by wire or radio, appears economically desirable, as does the use of "radar tracking."

ACKNOWLEDGMENTS

During the progress of this study valuable assistance in the field was received from local residents in all social and economic categories; the extremes being represented by Juan Tomas, aged and decrepit chief of the allegedly cannibal Seri tribe on Tiburon Island, and Sr. Alberto Celaya, Comisario of the prosperous Sonoita Oasis, in Sonora, Mexico. Discussions of the problems of desert weather and climate with the staff of the Desert Botanical Laboratory, in Tucson, Arizona, were found most helpful. During the preparation of this report a large amount of information was supplied the writer by the Servicio Meteorologico Mexicano and the United States Weather Bureau. This assistance, some of which required considerable special work, is here gratefully acknowledged.

CARTOGRAPHIC REFERENCES

Geographic nomenclature in this paper follows, wherever possible, that in Bartholomew, John, *The Oxford Advanced Atlas*, Oxford University Press, 1942.

Details of coastal waters, and descriptions of the various islands, are contained in H.O. 84, *Sailing Directions for the West Coasts of Mexico and Central America*, Washington (D.C.), 1937, eighth edition.

Land features adjacent to the hurricane area are mapped on a scale of 1/1,000,000 in the U.S. Coast and Geodetic Survey's *Western Hemisphere Pilotage Charts* (available from U.S. Coast and Geodetic Survey, Washington, D.C.) Code APC 3; 11M, *Death Valley;* 12M, *Mount Taylor;* 18M, *Guadelupe Island;* 15M, *Rio Grande;* 19M, *Cabo San Lucas;* 20M, *Lago Chapala;* 21, *Yucatan;* 24, *Revilla Gigedo Island;* 25, *Popocatapetl;* 26, *Honduras;* 30, *Lago Nicaragua;* 31, *Panama;* and 34, *Rio Cauca.* Similar coverage, on a scale of 1/3,000,000, is given by the *Long Range Air Navigation Charts,* Code ALR 1; 20, *California;* 21, *Mexico;* 31, *Clipperton Island;* and 32, *Central America.*

BIBLIOGRAPHIC REFERENCES

(1) TANNEHILL, I. R.: *Hurricanes: Their Nature and History.* Princeton University Press, Princeton. Many editions.

H.O. 160: *Sailing Directions for the Bay of Bengal.* Government Printing Office, Washington, D.C., 1941, 39–42.

ELIOT, Sir J.: *Handbook of Cyclonic Storms in the Bay of Bengal.* Government of India, Calcutta, 1901.

Serial publication, *Indian Monthly Weather Review.* Government of India, Calcutta.

(2) TANNEHILL, I. R., *op. cit.*

VISHER, S. S., and HODGE, D.: Australian Hurricanes and Related Storms. *Official Yearbook of the Commonwealth of Australia,* No. 16, 1923.

H.O. 169: *Australia Pilot, Vol. III.* Government Printing Office, Washington, D.C., 1930, p. 39.

TAYLOR, GRIFFITH: *Australian Meteorology.* Oxford University Press, 1920, p. 305.

(3) TANNEHILL, I. R., *op. cit.*

CLAXTON, T. F.: *Isotyphs Showing the Prevalence of Typhoons in Different Regions of the Far East for Each Month of the Year.* Hong Kong, 1932.

H.O. 125: *Sailing Directions for the Western Shores of the China Sea.* Government Printing Office, Washington, D.C., 1937, pp. 47–64 (" Required reading ").

H.O. 165: *Sailing Directions for the Pacific Islands, Vol. 1.* Government Printing Office, Washington, D.C., 1938, pp. 31–39; Vol. 2, 1940, pp. 37–40.

(4) TANNEHILL, I. R., *op. cit.*

MITCHELL, C. L.: West Indian Hurricanes and Other Tropical Cyclones of the North Atlantic Ocean. *Monthly Weather Review,* Supplement 24. Government Printing Office, Washington, D.C., 1924.

H.O. 130: *Sailing Directions for the East Coasts of Central America and Mexico.* Government Printing Office, Washington, D.C., 1939, pp. 37–50.

H.O. 129: *Sailing Directions for the West Indies, Vol. II.* Government Printing Office, Washington, D.C., 1938, pp. 35–49.

(5) VISHER, S. S.: Tropical Cyclones in the North-east Pacific between Hawaii and Mexico. *Monthly Weather Review.* Washington, D.C., 1922, pp. 295–297.

HURD, W. E.: *Pilot Chart of the North Pacific Ocean* (August, 1944); subtitled *Tropical Cyclones of the Eastern North Pacific Ocean.* U.S. Hydrographic Office, Washington, D.C., 1944.

HUMPHREYS, W. J.: *Physics of the Air.* New York, 1940, p. 175.

H.O. 84: *Sailing Directions for the West Coasts of Mexico and Central America.* Government Printing Office, Washington, D.C., 1937, pp. 34–38.

GOMEZ, J. C.: *Boletin Anual del Servicio Meteorologico Mexicano.* Tacubaya, D.F., Mexico, annually, 1936–1942. " Carta de Trayectorios de Ciclones Tropicales ".

See also other serial publications by the Servicio Meteorologico Mexicano, and by the U.S. Weather Bureau.

(6) Records of the various Manila Galleons are scattered through the libraries of half a dozen California Missions, and are also found in the Archivo Nacional in Mexico City and the Archivo General de las Indias in Spain. Much of the material is still uncatalogued, and varies from actual ships' logs to folklore.

(7) " Documentos Para La Historia de Mexico," published in Mexico City, in three series, most volumes undated, consists of a vast collection of mission and military reports and letters written during the time that Mexico was a colony of Spain. A considerable part of this material, covering the explorations by Eusebio Kino and by Juan Bautista de Anza, has been duplicated, by translation from the original documents, by Herbert E. Bolton, and published as *Kino's Historical Memoir of Pimeria Alta,* New York, 1919, Berkeley, 1948; and *Outpost of Empire,* Berkeley, 1931.

(8) Ives, R. L. (translator and editor) : *The Sonoran Census of 1730.* Records Amer. Catholic Historical Society, Philadelphia, Pa. (in press.)
(9) Hurd, W. R. : *Tropical Cyclones of the Eastern North Pacific Ocean.* U.S. Hydrographic Office, Washington, D.C., 1944.
(10) McGee, W. J. : *Sheetflood Erosion.* Bull. Geol. Soc. Amer., Vol. 8, 1897, pp. 87–112.
Ives, R. L. : *Desert Floods in the Sonoita Valley.* Amer. Jour. Science, Vol. 32, 1936, pp. 349–360.
Davis, W. M. : *Sheetfloods and Streamfloods.* Bull. Geol. Soc. Amer., Vol. 49, 1938, pp. 1337–1416.

TROPICAL CYCLONES OF THE WESTERN NORTH PACIFIC

By Captain Merle P. Woodall, U. S. Air Force

Air Weather Service units located at Harmon AFB, Guam ; Haneda AFB, Tokyo ; Kadena AFB, Okinawa ; Clark AFB, Manila ; and Kaingwan AFB, Shanghai, comprised the Typhoon Warning Network of the 2143d Air Weather Wing in 1947. The Haneda Weather Central was the Typhoon Warning Centre, charged with overall direction and operation of the Typhoon Warning Network until 1st September, at which time this function was transferred to Harmon Weather Central. The 514th Weather Reconnaisance Squadron (VLR) at North Guam AFB performed reconnaissance of typhoons beginning 1st September. This material is drawn from post-analysis reports made by the Typhoon Warning Network.

There were 26 tropical cyclones of sufficient intensity to warrant the exchange of Bulletins among the stations of the Typhoon Warning Network, Of these, 19 were of typhoon intensity (maximum winds over 65 K), and 7 of tropical storm intensity (maximum winds over 27 knots, but less than 66 K). From these records some observations on the origin, movement, and dissipation can be made.

The problem of anticipating the formation of tropical cyclones was not too difficult. Most of them were suspected several days in advance, and in all cases they were found in sufficient time to issue forecasts to interested agencies. According to analyses made, all tropical cyclones of 1947, except those which formed in the wake of another tropical cyclone, originated at the junction of an easterly wave and the ITC often intensified by a trough in the westerlies. In no case was one observed to form in a strictly homogenous air mass. Formation of typhoons did not appear to be limited to island areas.

Forecasting the movement of tropical cyclones was the most difficult problem encountered. No accepted method of forecasting was reliable in all cases, and using every technique available the path and rate of movement of many of the typhoons was impossible to forecast accurately. Even by post-analysis the path of Rosalind, or the deceleration of Gwen, is difficult to explain. To approach the problem of forecasting track and speed of movement, some new hypotheses on steering principles will be considered and the usually accepted rules examined.

The most popular method of predicting the movement of typhoons is by the use of the steering wind of the free air current. From a study of those in 1947 it was found that forecasting the movement of typhoons in the Pacific by the direction of flow of the free air current above the typhoon is practical only for those which do not extend above the 500 mb. level, since upper air data above that level is very sparse, and since it is doubtful if the free air current steers the very deep lows. Of the typhoons and tropical storms of 1947, in only three cases did the 700 mb. wind flow apparently steer the tropical cyclone. The 700 mb. wind flow was most valuable when the tropical cyclone began to become extratropical. Typhoons Gwen and Jean were typical.

It was shown that no one level can be selected for steering. Some tropical cyclones have a closed circulation extending above 40,000 ft., while others were definitely only 10,000 ft. and were easily steered by the 700 mb. winds. Each particular tropical cyclone must be analysed each day to find the proper level for steering.

A useful aid in forecasting the movement of typhoons is the asymmetrical distribution of wind velocities around the typhoon. The rule is this : if the wind is symmetrical, the typhoon is nearly stationary ; if the wind velocity varies in the different quadrants, the typhoon will move parallel to the strongest wind, and the speed of movement will be proportional to the difference between the wind speed in the strong quadrant and that of the weak quadrant. A simple explanation of this rule is as follows : in the strong quadrant the general steering current, or movement vector, is added to the cyclonic current of the typhoon ; in the weak quadrant the general current is subtracted from the cyclonic current.

This rule can be applied to some of the typhoons of 1947, although it was not generally used by the forecaster. Many reports note the variation in the distribution of wind speed around the typhoon. Clouds and weather are also often distributed asymmetrically. Transport aircraft as well as regular reconnaissance aircraft remarked on this feature frequently.

This principle seems to be another manifestation of the steering principle ; the steering current intensifies the side parallel to it, weakens the side opposed to it. However, there is an important difference in the application of the principle, and therefore some of the difficulties encountered in employing the steering effect of the free air current are avoided. No search need be made for the proper steering level and no attempt need be made to evaluate its force. The manifestation of the free air current is observed directly in its effect on the symmetry of the typhoon. Steering by the wind differential method is considered one of the best methods available. It has a theoretically sound basis, the determining factors can be observed, often without the aid of instruments, and its verification from actual use is relatively high.

The use of the surface synoptic map in steering was found quite useful, since the most data was available for these maps. In so far as the upper air situation can be estimated from the surface map, the use of the surface map is successful. (This may lead to a vicious circle, as in the case of Rosalind.) A point which must be kept in mind here is that the surface synoptic pattern is a function of the typhoon. The energy of the typhoon must be integrated with the forces controlling the synoptic picture to arrive at a forecast.

The present rules that typhoons dissipate rather rapidly after moving north of 30° N. latitude held up well in 1947. All of those which moved north of 30° N. in this year, only Donna, Gwen, Kathleen, and Rosalind had any significant life north of 30° N., and these weakened rapidly upon reaching and passing that latitude. An examination of climatological records for Japan also verify that typhoons almost never retain their severity, experienced at lower latitude stations such as Iwo Jima and Okinawa, upon reaching Honshu. This finding is somewhat different from on the eastern coast of the U.S., where hurricanes sometimes remain intense well above 30° N. latitude. A possible explanation of this difference is contained in the curvature of coast-line of south-west Honshu. It will be noted that the south-east coast of the islands has a definite convex curvature. It has been shown that low pressure systems approaching a convex coast line tend to weaken.

Extrapolation, climatology, and surface synoptic steering were investigated as methods of forecasting the direction and speed of movement of typhoons. Extrapolation was found to be useful, if applied to good data, especially either in the early or late parts of the season. Extrapolation was a very poor method of forecasting in those cases in which the present and past position of the typhoon were inaccurate, and also poor during July, August, and September, when the tracks are most erratic. Another difficulty in using extrapolation in forecasting the rate of movement was that many of the typhoons (notably Gwen, Kathleen, and Rosalind) did not accelerate upon recurving.

Climatology was especially useful in 1947. In many instances climatology was the only aid available, and late in the season during November and December the typhoons followed the tracks of climatological expectancy well. Of course, some difficulties were encountered in using the climatological data available. Tracks shown in different publications do not agree. Those shown in H.O. 219, " Climatology, Asia Air Station," appear incorrect, especially the average tracks shown for November, December, and January. Although climatology given in " Typhoon Tracks Supplement to Weather Guides for Long Range Planning," prepared by the War Advisory Council on Meteorology, U.S. Weather Bureau, March, 1944, covers a period of approximately twenty years, it apparently does not include all the possible variations.

In conclusion, some improvements that could be made to the typhoon warning service in the north Pacific should be pointed out. In order to devise better methods of forecasting the direction and movement of typhoons detailed study of future typhoons is necessary. Post analysis reports are necessary, similar to that made by Kidd and Reed and this report. The 2143d Air Weather Wing has directed that the Harmon Weather Central prepare an annual report of this type. But these reports can only do a portion of the task. Many of these reports lack valuable data from the P.I., China, and Indo-China. A first step would be to establish an effective exchange among all agencies of new data for post-analysis purposes.

Discussion

Mr. Simpson pointed out that the reasons for certain anomalous typhoon tracks could sometimes be found in the filling or deepening of upper level troughs, perhaps by the mechanism of wave transfer of energy given prominence by Namais. Mr. Gringorten pointed out that there were difficulties in using the simple diagrams in which the direction of motion of a typhoon is obtained by vector addition of a cyclonic current and a general carrying current.

Mr. Mordy also pointed out that this idea appeared to involve inflow to the south of the typhoon and outflow to the north, which was contrary to experience.

In connection with Captain Woodall's statement that convection should not be over-emphasized in the formation of tropical storms, most of which formed over the open sea and not over islands, Mr. Green remarked that in his experience convention was always active in the formation of the storms, but was often provided by tropical convergence zones and not by islands.

TYPHOON FORECASTING AT THE ZI-KA-WEI OBSERVATORY

By Rev. Fr. E. Gherzi, S. J., Director for Meteorology and Seismology

We believe that a tropical cyclone (a typhoon) forms out of convection-instabilities in the extreme southern border of the Pacific Ocean air mass—namely, in the Doldrums—the "embroidery of the trades," as it has been called by Sir Napier Shaw.

These convection-instabilities are a common event over the numerous islands dotting that region which extends from lat. 5° to lat. 15° north of the Equator.

These convection-instabilities by themselves cannot become typhoons. A kinetic factor is required. This kinetic factor we have found in the intermittent but powerful displacements of the Pacific air mass from east to west. The reason for the bodily motions of such an enormous portion of the troposphere is still a mystery.

These convection-instabilities, being driven westward, will often, if sufficiently intense, amalgamate to form a larger area of convection, moving westward. The Coriolis force will cause this area to spin and take on the aspect of a tropical cyclone.

These two factors—thermic and kinetic—seem to us sufficient to explain the formation of a tropical cyclone or typhoon. No "triple point situation" or two different air currents interacting are required. These two last atmospheric conditions might perhaps explain the intensifying or the blocking of a typhoon, already formed and already on its track. Such an outside atmospheric interference might also, later on, transform the tropical cyclone into an extra-tropical cyclone, with definite fronts in its structure.

An interesting datum, never quoted, and one which meets our thermic explanation of the birth of a typhoon is that the temperature in the centre of a tropical cyclone is and remains the same as that of the original convection area—namely, about 27° c. So much so that a typhoon seems cool to the Shanghai people, while it appears warm in the Tokyo region. When the temperature of the centre of a typhoon falls down below 24° c. the storm degenerates rapidly into an extra-tropical cyclone.

Our theory also explains why, when the typhoon fills up, it becomes again a thundery disturbance, with CuNi instead of the usual StratoNi. We have no knowledge of an extra-tropical cyclone showing the same evolution, when it becomes occluded or filled up, although in an extra-tropical cyclone, contrary to what happens in a full-fledged typhoon, there are always thundery conditions in the S.W. and the N.W. sectors. These extra-tropical cyclones can easily be located by direction-finders, while only the outside border of the typhoon can be followed by this means.

The future motion of the cyclone can be deduced from the trend of the isobars of the anticyclonic part of the Pacific air mass, to which the cyclone is, so to speak, attached (at least in a normal weather situation). A typhoon detached from its driving air mass will degenerate quite rapidly.

These isobars have been drawn since 1930 for the 3,000 m. level by means of the well-known Laplace formula, using the simultaneous surface observations from the reporting stations and admitting a temperature lapse rate of 0. 6° c. per hundred meters. This weather map drawn for the 3,000 m. level will often show a ridge of high pressure over the surface location of the cyclone, extending sometimes 1,000 km. westward. Pilot balloon soundings have shown this N.E. trade wind current reaching even the Gulf of Bengal, when a typhoon was nearing the Island of Luzon, moving westward. However, this upper level map will show the real track along which the typhoon will move for the next twelve hours. We do not think it possible to forecast its motion for the next twenty-four hours.

We have chosen the 3,000 m. level because of special seismological registrations obtained during typhoon weather. As far back as 1924 we correlated the presence of " group-microseisms " showing a constant proper period of 4 to 6 seconds, independent of the amplitude, with a typhoon over our neighbouring seas. These microseisms were never registered when high seas, raised by the strong anticyclonic winter monsoon gales, were breaking over the rugged Chusan Islands some 80 miles from Zi-Ka-Wei. But as soon as a tropical storm was located even at 1,000 km., these special tremors were clearly obtained.

This period of 4 to 6 seconds, for a single vibration, was registered by means of seismographs of very different proper periods, although always longer than 5 s. We considered this period of vibration as being, approximately, the period of vibration of the column of the cyclone, progressing over the ocean and oscillating under the pressure of the Pacific air mass aloft. The fierce rain and wind squalls were also found to have a decided period between 4 and 6 s. putting out of action, by resonance, any high structure, vibrating with proper period of 4 to 6 seconds.

If a typhoon on a westerly track appears to be recurving northward or northeastward the trend of the 3,000 m. level isobars will show whether the Pacific air mass is withdrawing eastward (recurve to the north-east) or remains stationary (recurve to the north).

Another kind of puzzling but very efficient correlation has been in use at Zi-Ka-Wei since 1938 for ascertaining the future motion of a typhoon already located by the usual means.

If radar pulses are sent out on the mean critical frequency for the E layer reflexions (around 6 megacycles at Zi-Ka-Wei) a very useful correlation has been found which helps greatly in deducing whether the Pacific air mass, driving the typhoon, will continue westward or whether it will remain stationary or recede eastward.

If while the typhoon is over the Eastern Sea we obtain in daytime after sunrise and before sunset echoes, from the E layer, these are strictly, although mysteriously, correlated with the westward advance of the Pacific air mass.

On the other hand, if, while a typhoon is located over the Eastern Sea, we get reflections from the F layer, this means a coming invasion of Siberian air (or the slowing up of Siberian air if already present over our region) and that the typhoon will not move westward in the next twenty-four hours, but will recurve around the border of the Pacific air mass, over the Eastern Sea. The intensity of the echoes seem to show the future intensity of the Siberian air mass.

Of course, this correlation is good only for the Shanghai region, and for such a method of forecasting to apply the typhoon should not be more than 300 or 400 miles in any direction.

As a consequence of our conception of the cyclone chimney being from 2 to 4 km. high, we advised the pilots of the Chinese air lines as early as 1936 to fly above any typhoon which would be on the track of their flight. We had an Italian Navy plane, Savoia-Marchetti type, passing over a typhoon near Foochow in 1935. The pilots reported blue skies all above them (they flew at 4, then at 5 km. height) with a very strong horizontal current aloft, flowing in the direction of the movement of the typhoon.

While admitting that elsewhere typhoons and tropical cyclones can be higher, we would like to know what results have been obtained by the pilots of the Australian air lines. In the Far East we have had more than ten cases in which a plane, flying not far from a typhoon, found " stratified air " and cloudy to blue skies above 8,000 or 10,000 ft.

DISCUSSION

Messrs. Simpson and Hutchings both stressed the variations that could take place from typhoon to typhoon and from place to place, and other speakers brought forward more evidence to support Father Gherzi's contention that sometimes typhoons were phenomena of very low levels. It was agreed, however, that this was not the general rule.

With regard to Father Gherzi's ideas of the steering of typhoons by the thermal wind or wind at some upper level, the opinion seemed to be that thermal steering was a useful concept, but that the level of steering was likely to vary greatly according to the stage of development of the typhoon.

Mr. Simpson presented some conclusions to show that the typhoons would move along the tongues of warm air as shown by the isopleths of mean virtual temperature between the 700 and 500 mb. levels.

Mr. Priestley pointed out the danger of applying thermal steering concepts depending on the geostrophic wind to typhoons in low latitudes.

ON THE THEORY OF TYPHOON FORMATION

By S. Aoki

SYMPOSIUM ON GENERAL METEOROLOGY OF THE PACIFIC IN TEMPERATE AND HIGHER LATITUDES

PRESSURE PATTERN FLIGHT PLANNING OVER THE PACIFIC

By Irving Gringorten,

Base Directorate for Geophysical Research, U.S. Air Force

Introduction

" Pressure pattern flying " is a generally accepted term to describe a system of navigation by air over long distances so as to take advantage of the existing wind fields. Since most flying has been over the temperate latitudes, where the winds can be assumed to be geostrophic, it had been found convenient to work with the known pressure fields instead of wind fields. However, at this conference, where we are engaged in the problems common to all countries that border upon the Pacific Ocean, from equatorial to both polar regions, it would seem more appropriate to call this subject " wind pattern flying," because the winds cannot be assumed to be given by the pressure fields for about 20° of latitude on either side of the Equator. " Wind pattern flying," therefore, will be considered the subject of this paper.

In the past there have been several methods frequently used in wind pattern flying. Some airlines that schedule trans-oceanic flights define six or seven simple tracks between point of departure and destination, and then use a rapid method for finding which of the tracks requires the least flying time.

Some airlines use another method of navigation, known as " Single Heading Flight," in which the airplane is kept on one precomputed heading from point of departure to destination. Such navigating has had several advantages. But the essential advantage of single heading flight is in the saving of flying time. This is accomplished because the forward motion of the airplane is not cut down by the airplane's crabbing into the wind. In order to stay on the straight-line path between point of departure and destination, the airplane must first of all crab to the left, then crab to the right, then head-on course, and so on. But, by crabbing to the right or to the left, the forward speed is only a component of the airplane's total airspeed. On the other hand, in single-heading flight, there is little or no crabbing, so that the forward motion is practically the full airspeed of the airplane.

But there are several limitations to the use of single-heading flight as it has been practised so far. First of all, the one proper heading has been computed from the existing or forecast pressure fields, instead of the wind fields, it having been assumed that the winds are geostrophic. This assumption is not true for flights that cross or come near the Equator. Secondly, there has been no adequate method of plotting the expected path of the airplane. Thirdly, if the flight be long, say 3,000 nautical miles, then the use of a single heading in itself offers no advantage of simplicity to the navigator, unless the heading is a single magnetic heading. (In this latter case the navigator would keep only one reading on his magnetic compass.) But in the past single heading has implied single *true* heading with respect to geographic north.

Lastly, there is no basis for the belief that the single-heading flight track is always the track of shortest flying time.

The one contributing factor to the shortening of flying time, which single-heading flight neglects, may be referred to as *tailwind shear*. Let us assume that the winds are tailwinds for a particular flight, but the winds increase in strength to the right of the general path of the airplane. Then, while the single-heading track would take the airplane along the straight-line from point of departure to destination, yet it is clear that a time-saving would be realized if the airplane were to be flown over a seemingly devious route, to take advantage of stronger tailwinds.

The above consideration leads us to a study of the *minimal* or shortest-time flight path. This was the subject of several papers that have appeared in the German mathematical literature back in 1931. Several authors, in particular Levi-Civita, obtained the formula for a flat earth

$$d\theta/dt = \delta v/\delta n$$

where $d\theta/dt$ is the rate of change of the heading of the airplane, and $\delta v/\delta n$ is the rate of increase of the tailwind across the path of the airplane. Two or three years ago the United States Air Force Weather Service tackled the problem of extending this theory to the spherical earth. The result of the mathematical investigation was the revised formula for the minimal flight path

$$d\theta/dt = \delta v/\delta n + \frac{c + v}{s}\,\delta s/\delta n$$

where the additional term introduces c, the airspeed of the airplane, and s, the scale factor of the chart that is used for representing the earth's surface. If all the headings, θ, are referred to the great circle, or the shortest path between the airports, then the additional term on the right would vanish.

In order to begin our considerations of the optimum flight paths over the Pacific, let us choose some hypothetical routes. Let us assume that regular flights are made between the airports San Francisco, Tokyo, Singapore, Auckland, Honolulu, Bogota, and New Year's Island. While these supposed flights are longer than the usual flights of to-day, we shall project them into the future when airplanes will be bigger, faster, and longer-ranged. Let us assume that the flights take place at 20,000 ft., airspeed 300 knots.

The shortest-time flight paths would be great circles except for the winds. Between Tokyo and San Francisco the winds are westerlies, on the average. Let the airplane be flown on a single heading with respect to the great circle. How should the single heading be found and how should the expected track be plotted? Briefly, it can be explained as follows: Let us accept an approximate path, such as the great circle itself. Divide this path into legs of about 200 to 400 nm. each. Over each leg there will be an average wind. It will be an easy matter, with a suitable computer, to obtain the cross-wind component. It is this component which will drift the airplane to the right or to the left of the direct path, the amount of drift being directly proportional to the length of the leg and inversely proportional to the forward speed of the airplane. Let us compute this drift for each leg of the flight and add several computations to obtain the overall drift. This overall drift will then provide the navigator with the proper heading.

Next, to plot the expected track, one simply needs to determine how much the airplane will have drifted at the end of each leg and to find successive points along the expected track.

The single-heading tracks with respect to the great circles can be converted into another set of tracks, the single-magnetic-heading tracks. The significance of these tracks is that a plane could be flown automatically, or without the attention of a pilot. At the same time this single-magnetic-heading flight offers the same advantages as general single-heading flight, especially by lessening flying time. By plotting all the tracks one can see that the single-magnetic-heading tracks lie reasonably close to the great circles for several of the routes. It is the recommendation of this paper that such long-range flights be made by use of single magnetic heading, except for extreme routes like the route between Auckland and New Year's Island, Tokyo, and San Francisco. For these last-mentioned routes the minimal flight paths are now considered.

Auckland to New Year's Island: The trip from Auckland to New Year's Island is best shown on oblique Mercator projection. The time-saving by single grid heading is about one hour. If the wind field were accurately known, it would be possible to determine wind shear and obtain the minimal flight path by which a still greater saving in time could be realized.

Tokyo to San Francisco: Using the pressure field we plot two single-grid-heading flights on an oblique Mercator projection between San Francisco and Tokyo. The route is sufficiently far north to permit the use of geostrophic wind. Wind shear can be easily computed. Thus, the minimal flight paths can be plotted. By flying this path, an airplane which would normally take about seventeen hours to fly from San Francisco to Tokyo would cut about thirty-five minutes from its time.

DISCUSSION

Dr. Spilhaus remarked that the vertical wind shear was more important than the horizontal wind shear, and should be taken into account in estimating the paths of shortest time. Dr. Gringorten in reply said that that was so, yet navigators preferred the flight at a constant level and much more work was necessary if flight paths with varying altitudes were to be introduced. Dr. Spilhaus further remarked that the chart used by Dr. Gringorten, an oblique Mercator projection, had to be specially constructed for each pair of points used as arrival and departure terminals for the aircraft. Dr. Gringorten agreed, but claimed that the extra time spent on constructing the charts was well worth while.

Colonel Moorman pointed out that flight paths are now fixed by the location of airfields and navigational aids. Thus only in special cases when time was of greatest importance would it be justifiable to deviate from these prescribed paths.

DYNAMIC CLIMATOLOGY AS A TRAINING AID IN THE WESTERN NORTH PACIFIC AREA

By Captain William Best, U.S. Air Force

The United States Air Force maintains weather installations in Japan, Korea, eastern China, and the adjacent waters and islands of the north-west Pacific Ocean. Meteorologists serving at these stations consider as their operational area the entire East Asia - North-west Pacific sector, and rotate on duty tours lasting from thirty to thirty-six months. This is a relatively short period, especially if we admit that local experience is necessary in gaining analysis and forecast proficiency.

The problem of forecaster orientation is an important one—namely, how to give the new forecaster in a minimum of time the maximum familiarization with East Asia - North-west Pacific weather.

An examination of the usual methods of orientation and training, such as studying past analyzed weather situations and studying meteorological texts and reports on regional weather, finds them insufficient. This is due primarily to the sparse synoptic data available (particularly in the upper air), and secondarily to the haste and/or lack of integration of weather research performed over the last decade.

As a training aid, an attempt has been made to compound a dynamic climatology of the area, consisting of an analysis of—

(1) The climatic controls and influences; and

(2) The typical weather processes which develop when the laws of meteorology are superimposed upon them.

The eight factors in such a climatology (at least as a preliminary definition) are terrain, ocean currents, the monsoon circulation, airmasses, extratropical cyclones, migrating anticyclones, the polar trough-polar front, and the descriptive weather types.

In the training procedure, the first seven factors are discussed and evaluated at length, with emphasis on (*a*) their mutual interaction, (*b*) their seasonal and within-season variation, and (*c*) their weather effects over the forecast area and how they can be exploited for map analysis and forecasting, even in the absence of adequate synoptic data coverage.

The descriptive weather types are an attempt to separate weather sequences into homogeneous groups, in the sense that all sequences belonging to one type develop from similar causes, appear alike on weather charts, and have similar effects. Their value is four fold—

(1) They familiarize the new forecaster with typical weather sequences.

(2) Because they are based on a finite number of weather combinations, rather than assuming that "anything is possible," they lend objectiveness to analysis and forecasting.

(3) The analysis of types and how to forecast them points out weak spots in our forecast techniques, and thus suggests lines of research.

(4) They represent an integration of the dynamic climatological factors over a large forecast area.

Charts A to G show the basic features of each of the seven basic weather types.

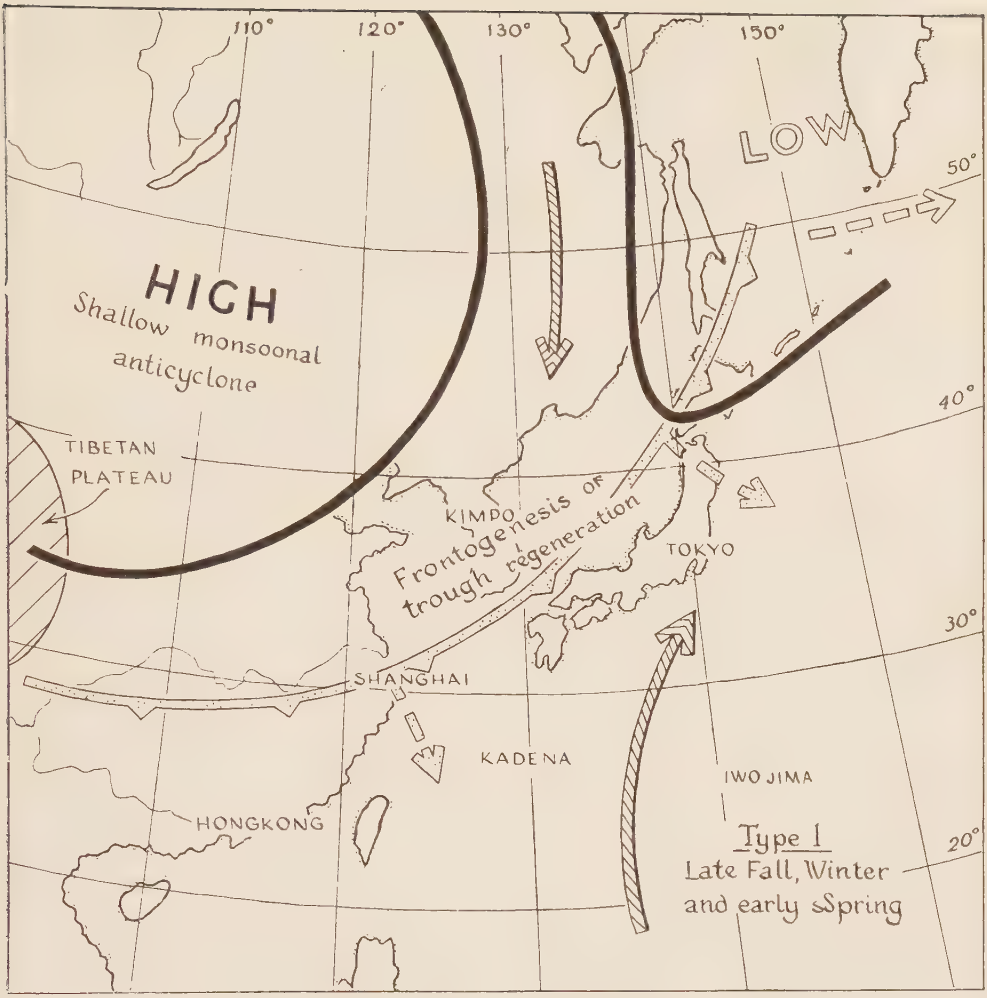

110°
120°
130°
150°
50°
40°
30°
20°
HIGH
Shallow monsoonal anticyclone
LOW
TIBETAN PLATEAU
KIMPO
Frontogenesis or trough regeneration
TOKYO
SHANGHAI
KADENA
IWO JIMA
HONGKONG
Type 1
Late Fall, Winter and early Spring

CHART A: Dashed arrow line-trajectory. Hachured arrow line-gradient air flow.

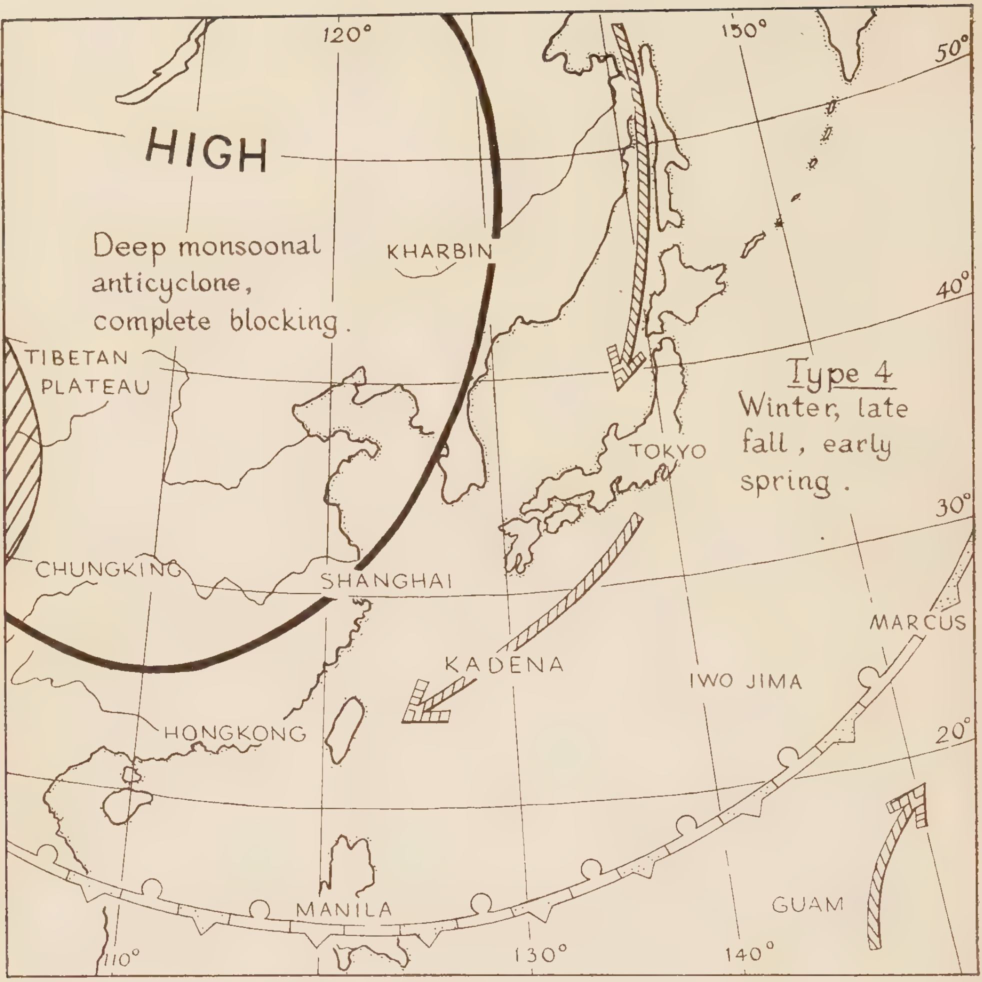

120°
150°
50°
HIGH
Deep monsoonal anticyclone, complete blocking.
KHARBIN
40°
TIBETAN PLATEAU
Type 4
Winter, late fall, early spring.
TOKYO
30°
CHUNGKING
SHANGHAI
MARCUS
KADENA
IWO JIMA
HONGKONG
20°
MANILA
GUAM
110°
130°
140°

Chart B: Hachured arrow line-gradient air flow.

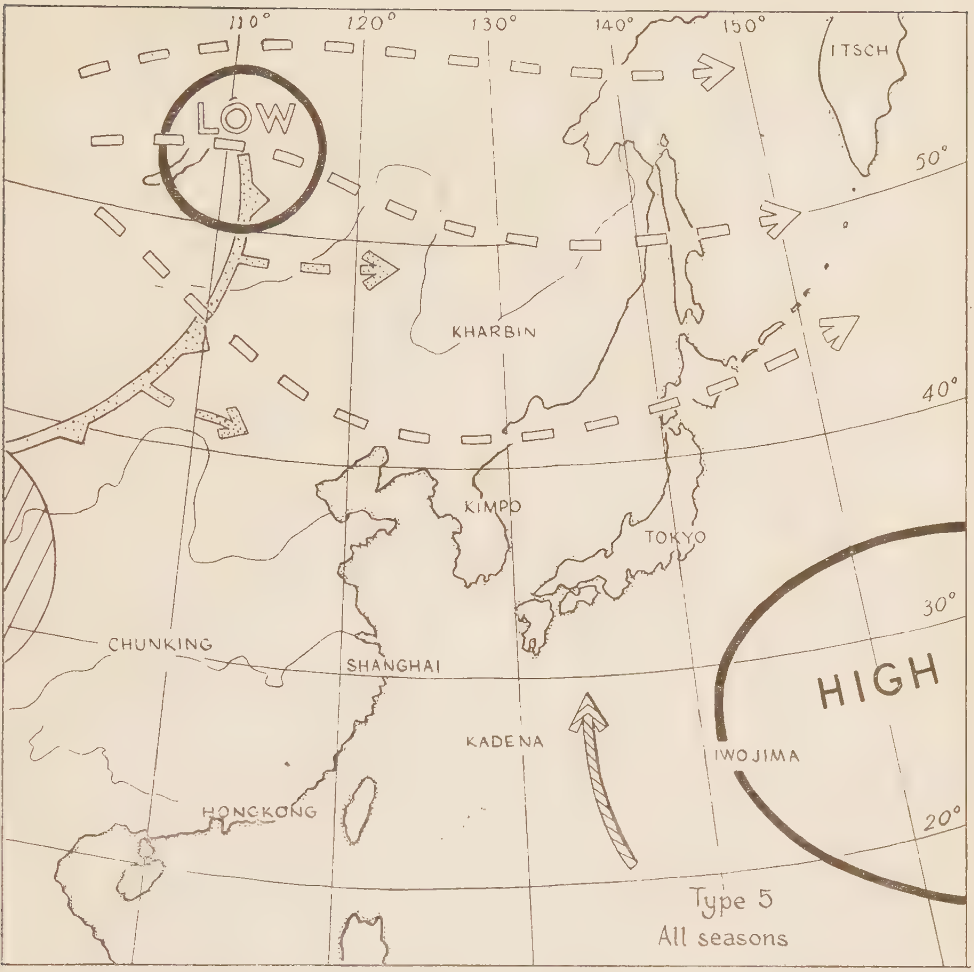

110°
120°
130°
140°
150°
ITSCH
LOW
50°
KHARBIN
40°
KIMPO
TOKYO
30°
CHUNKING
SHANGHAI
HIGH
KADENA
IWOJIMA
HONGKONG
20°
Type 5
All seasons

CHART C: Dashed arrow line-trajectory. Hachured arrow line-gradient air flow.

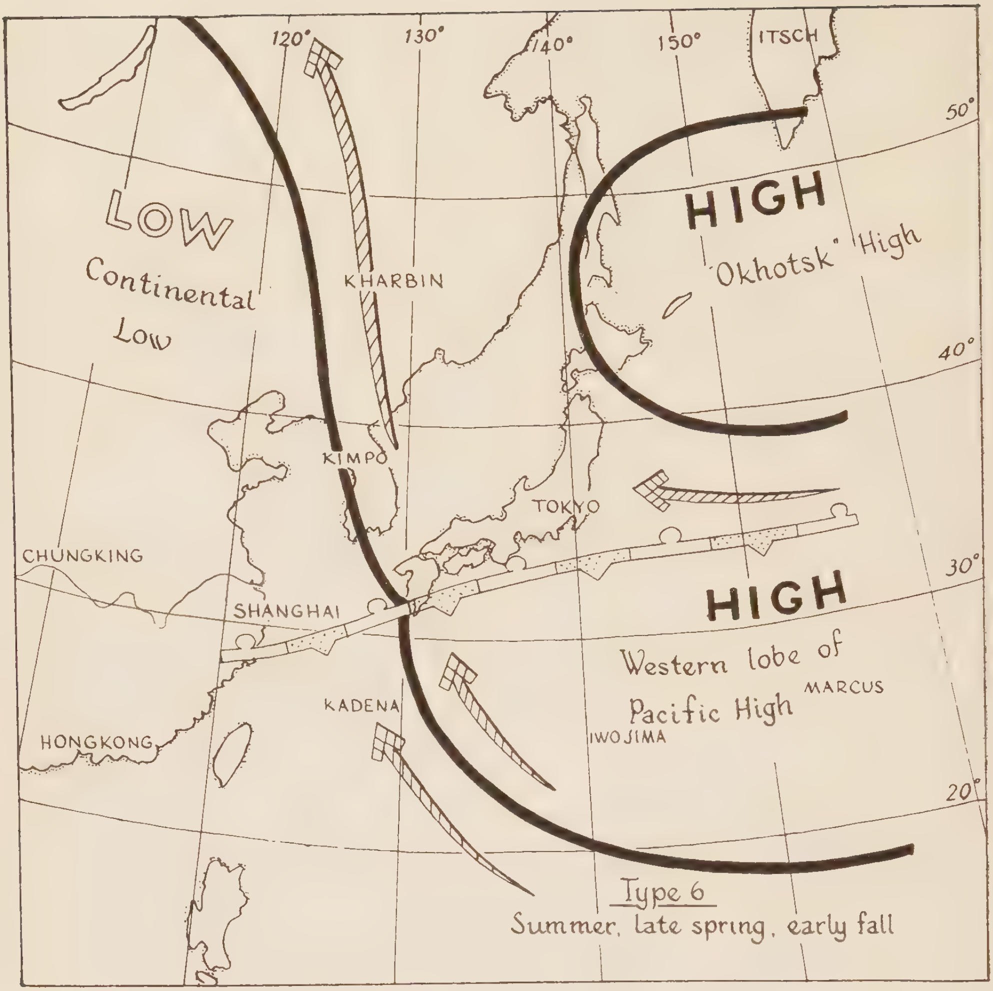

120°
130°
140°
150°
ITSCH
50°
40°
30°
20°
LOW
Continental
Low
HIGH
"Okhotsk" High
KHARBIN
KIMPO
TOKYO
CHUNGKING
SHANGHAI
HIGH
Western lobe of
Pacific High
MARCUS
KADENA
IWO JIMA
HONGKONG
Type 6
Summer, late spring, early fall

CHART D: Hachured arrow line-gradient air flow.

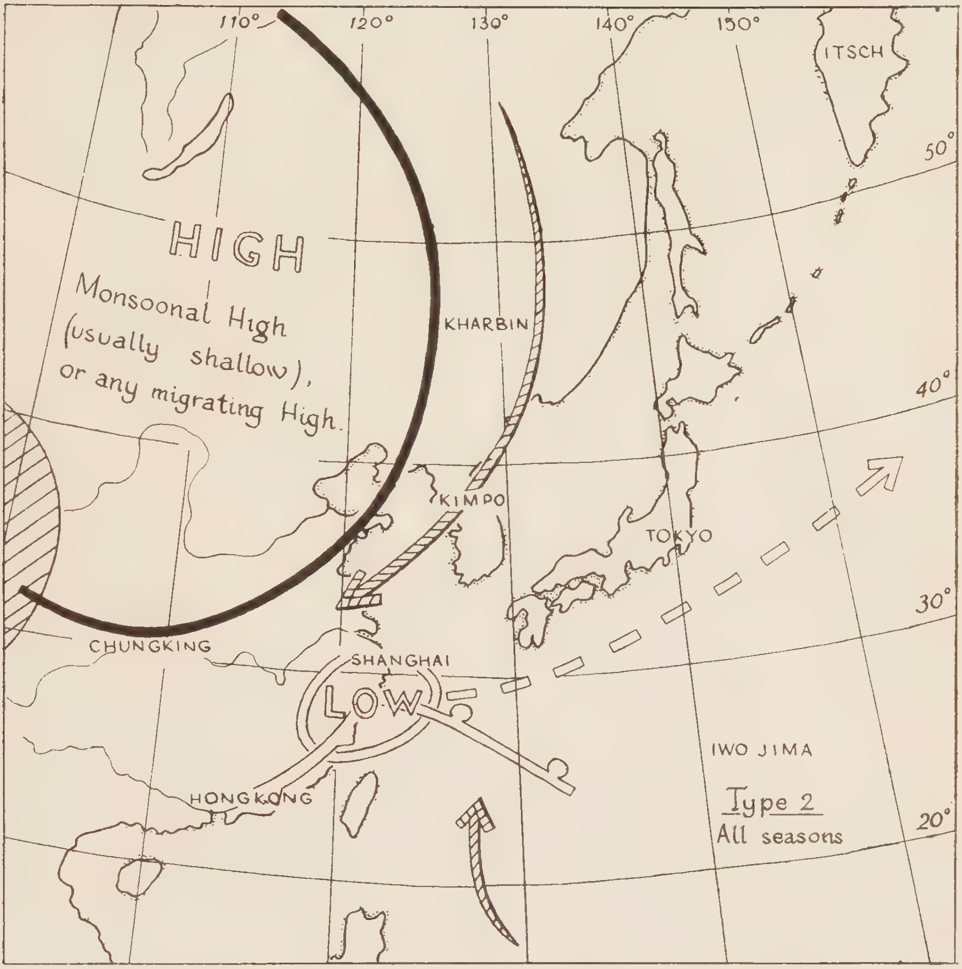

110°
120°
130°
140°
150°
ITSCH
50°
HIGH
Monsoonal High (usually shallow), or any migrating High.
KHARBIN
40°
KIMPO
TOKYO
30°
CHUNGKING
SHANGHAI
LOW
IWO JIMA
HONGKONG
Type 2
All seasons
20°

CHART E: Dashed arrow line-trajectory. Hachured arrow line-gradient air flow.

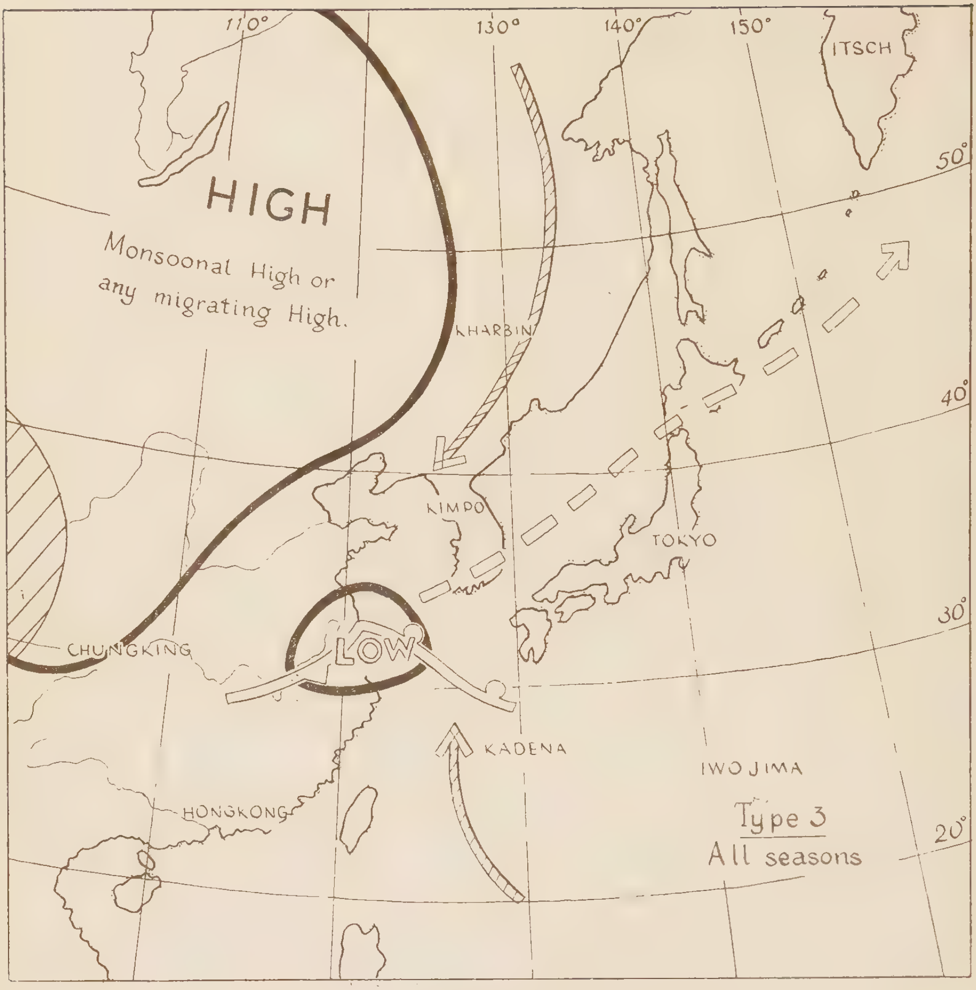

110°
130°
140°
150°
ITSCH
50°
40°
30°
20°
HIGH
Monsoonal High or any migrating High.
KHARBIN
KIMPO
TOKYO
CHUNGKING
LOW
KADENA
IWO JIMA
HONGKONG
Type 3
All seasons

Chart F: Dashed arrow line-trajectory. Hachured arrow line-gradient air flow.

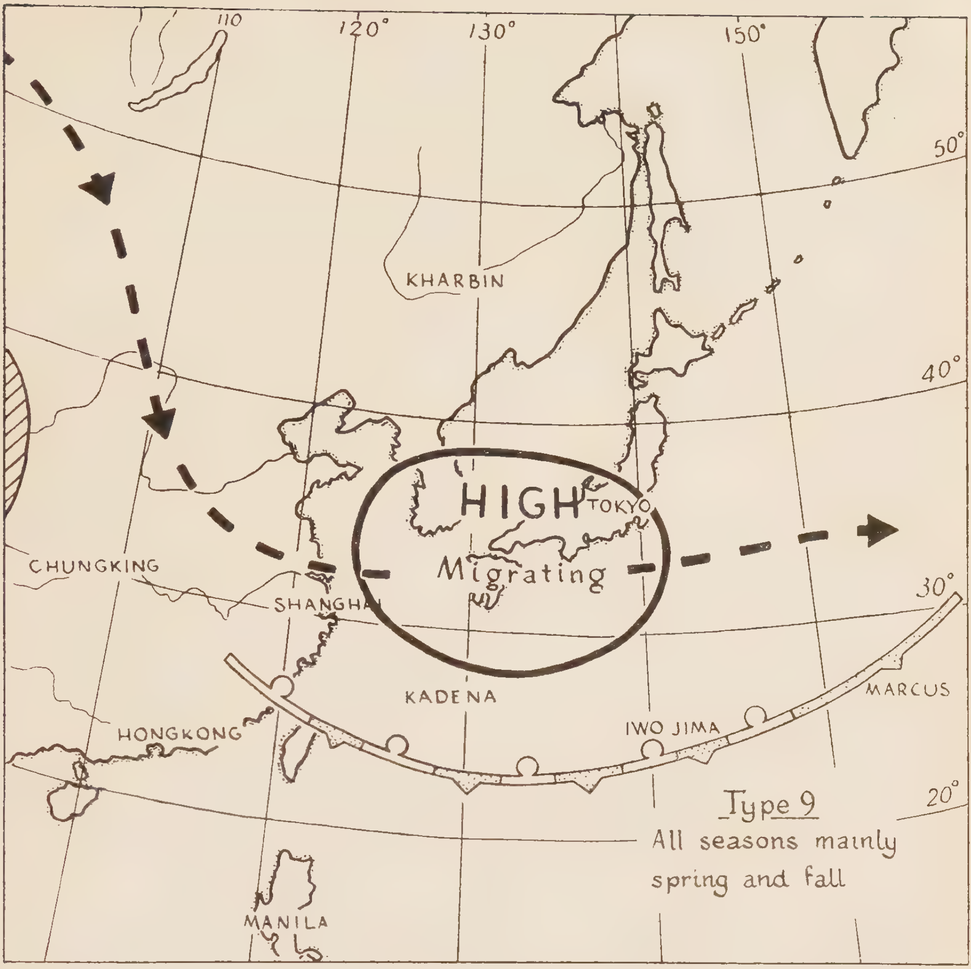

110
120°
130°
150°
50°
40°
30°
20°
KHARBIN
HIGH
TOKYO
Migrating
CHUNGKING
SHANGHAI
KADENA
MARCUS
IWO JIMA
HONGKONG
MANILA
Type 9
All seasons mainly
spring and fall

CHART G: Dashed arrow line-trajectory.

REFERENCES

CIT–AAF Research Unit: *Preparation of a Classification Graph East Asia – West Pacific Synoptic Region, Jan., 1899–June, 1939.* H.Q., A.A.F., 1944.

HSIA-CHIEN HUANG: *Frontogenetic Regions in the Far East.* 1937.

ORTON, R. B.: *The Paths and Characteristics of Migratory Anticyclones in South-east Asia.* U.S.A.A.F. Weather Central, Hsinching, China, 1945.

H.Q., A.A.F., Report 890: *Weather and Climate of China, Parts A and B.* March, 1945.

Haneda Weather Central, Tokyo, Japan. Unpublished papers, 1947–48.

Colonel Moorman said that this dynamic climatology of the area served mainly in training analysts and forecasters and the system of descriptive weather types presented by Captain Best could not be used entirely for daily forecasting activities.

Mr. Priestley was interested to see that in the East Asia area the migratory anticyclones existed with period almost identical to that in the southern hemisphere. He felt it would be useful if some work were done on these anticyclones analogous to the work of Kidson in the southern hemisphere.

SELECTED ANALYSES FOR THE SOUTHERN OCEAN AND THEIR IMPLICATIONS IN SOUTHERN HEMISPHERE CIRCULATION

By W. J. GIBBS, Australian Meteorological Service

[*Abstract* (¹)]

The establishment of meteorological observing points at Marion, Heard, and Macquarie Islands has provided a unique opportunity for the study of meteorological elements at these localities. Although the distances separating the observations are great, the fact that frequent reports are made and that radiosonde data are available makes possible a generalized synoptic analysis of the Southern Ocean. These analyses have important bearing on the analysis over the Australian Continent modifying considerably some existing frontal concepts. The implications of these analyses in the general circulation of the Southern Hemisphere are briefly discussed.

PREFERRED POSITIONS FOR CYCLOGENESIS IN THE AUSTRALIAN AND TASMAN SEA AREA

By J. W. LILLYWHITE, Australian Meteorological Service

Abstract

The effect on the general circulation over Australia in particular, and the South Pacific Ocean generally, of secondary cyclones which develop in mid-latitudes over and near the Australian mainland is discussed, and the importance to forecasting of advance knowledge of their development is emphasised.

A statistical examination of fully analysed Australian synoptic charts for two sample years shows that certain regions are " preferred positions " for the formation of these secondary features of the circulation. Neglecting the tropics, the most noteworthy regions are found to number four—

(1) An elongated area lying parallel to and one to two hundred miles inland from the west coast of Western Australia.
(2) The " head " of the Great Australian Bight, approximately lat. 30° S. ; long. 130° E.
(3) Waters within one to two hundred miles to the west, south, and south-east of Tasmania.
(4) The central Tasman Sea, approximately one to three hundred miles south of Lord Howe Island.

---

[1] The full paper is to be published in the " Weather Development and Research Bulletin " of the Australian Meteorological Service.

Typical cases of the development of cyclones in these areas are analysed, and it is shown that in each area the normal temperature distribution combines with the topography to produce a latent cyclogenetic field, which under favourable conditions gives rise to actual cyclogenesis. Two important factors contributing to the development of active cyclones are (*a*) the passage of a deep cyclone far to the south travelling east in the region of lat. 50° to lat. 60° S., and (*b*) the formation of a " coastal front " in western and southern Australia during the summer months.

The subsequent movement of the secondary cyclones is shown to be controlled by thermal steering from the upper air, and to be usually in an E.S.E. direction. Their future development and influence on the general circulation of the South Pacific is briefly stated.

The following table gives the frequency distribution of cyclogenesis (frontal waves) in six preferred positions in the Australian and Tasman Sea Region.

(Period : Two Years)

<table>
<tr><th rowspan="2">Position.</th><th colspan="2">Summer.</th><th colspan="2">Winter.</th><th rowspan="2">Year.</th><th rowspan="2">Percentage.</th></tr>
<tr><th>Oct. to Dec.</th><th>Jan. to March.</th><th>April to June.</th><th>July to Sept.</th></tr>
<tr><td rowspan="2">(1) S.E. Indian Ocean bounded by lat. 25 and 35° S.; long. 105 and 115° E.</td><td>2</td><td>8</td><td>3</td><td>8</td><td rowspan="2">21</td><td rowspan="2">7</td></tr>
<tr><td colspan="2">10</td><td colspan="2">11</td></tr>
<tr><td rowspan="2">(2) S.W. quarter of Western Australia—250 mile wide strip from W. coast between lats. 25 and 35° S.</td><td>24</td><td>15</td><td>9</td><td>15</td><td rowspan="2">63</td><td rowspan="2">23</td></tr>
<tr><td colspan="2">39</td><td colspan="2">24</td></tr>
<tr><td rowspan="2">(3) The " head " of the Great Australian Bight bounded by lats. 25 and 38° S.; longs. 123 and 133° E.</td><td>10</td><td>12</td><td>12</td><td>15</td><td rowspan="2">49</td><td rowspan="2">17</td></tr>
<tr><td colspan="2">22</td><td colspan="2">27</td></tr>
<tr><td rowspan="2">(4) Tasmanian region—W., S., and E. of Tas. within 200–300 miles of coast</td><td>16</td><td>13</td><td>14</td><td>9</td><td rowspan="2">52</td><td rowspan="2">18</td></tr>
<tr><td colspan="2">29</td><td colspan="2">23</td></tr>
<tr><td rowspan="2">(5) Central N.S.W. and Northern Victoria (west of mountains)</td><td>13</td><td>10</td><td>3</td><td>6</td><td rowspan="2">32</td><td rowspan="2">11</td></tr>
<tr><td colspan="2">23</td><td colspan="2">9</td></tr>
<tr><td rowspan="2">(6) Central and western Tasman Sea bounded by lats. 32° and 40° S ; long. 165° E. and east coast of Australia</td><td>17</td><td>8</td><td>11</td><td>14</td><td rowspan="2">50</td><td rowspan="2">18</td></tr>
<tr><td colspan="2">25</td><td colspan="2">25</td></tr>
<tr><td rowspan="2">(7) Other areas .. ..</td><td>5</td><td>5</td><td>4</td><td>3</td><td rowspan="2">17</td><td rowspan="2">6</td></tr>
<tr><td colspan="2">10</td><td colspan="2">7</td></tr>
<tr><td rowspan="2">Total .. ..</td><td>87</td><td>71</td><td>56</td><td>70</td><td rowspan="2">284</td><td rowspan="2">100</td></tr>
<tr><td colspan="2">158</td><td colspan="2">126</td></tr>
</table>

DISCUSSION

In reply to a query by Captain Best, Mr. Lillywhite said that tropical continental air generally moved out from Australia aloft in a north-west to south-east direction.

Some of the figures given by Mr. Lillywhite were confirmed by Mr. Kerr, who presented similar results for the north Tasman Sea and Tasmanian region.

Captain Best then raised the question as to whether these depressions might possibly develop aloft and not at the surface. Mr. Lillywhite agreed that this was so, and Mr. Hutchings pointed out that the depressions of the Lord Howe Island region very frequently developed aloft over Northern Queensland. Mr. Hutchings pointed out that the northerly component in the tracks of these lows indicated that they were possibly of non-frontal origin.

SOME MEASUREMENTS OF EARTH TEMPERATURE AND SOIL CONDUCTIVITY IN NEW ZEALAND

By J. W. HUTCHINGS, New Zealand Meteorological Service

INTRODUCTION

IT has often been emphasized that the standard meteorological practice of measuring earth temperatures at a fixed hour of observation such as 9 a.m. fails to take account of the very large diurnal changes that occur near the surface of the soil. It may also be pointed out that these changes are of great importance to agriculture and in many other aspects of the economic life of the country. Moreover, measured values of soil temperature and conductivity are of interest in various geophysical investigations and play an important part in certain meteorological problems involving the exchange of heat between the earth and the atmosphere.

PART I—THE OBSERVATIONS AT EARNSCLEUGH

Instruments and Site at Earnscleugh

As part of the investigation into frost forecasting in Central Otago a Negretti and Zambra mercury-in-steel thermograph was installed at the New Zealand Government Research Orchard at Earnscleugh, and records from this instrument are now available from May, 1947. In installing the bulbs of the thermograph in the earth a short trench 2 ft. or 3 ft. wide was dug, one side of the trench being 3 in. deep and the other side 5 in. deep. The removed soil was then carefully filled in so as to be packed around the elements, and the surface of the soil was then pressed down and levelled. A sparse cover of short grass gradually appeared as natural vegetation, and to all appearances the plot could not be distinguished from the surrounding area of ground. Making allowance for natural consolidation of the ground, it was thought that the above procedure would result in the centres of the thermograph bulbs being at depths of 3 in. and 5 in respectively in relatively undisturbed soil with a natural vegetation cover appropriate to climate of the district. These values were later checked by excavation of the elements and careful measurement of their depths. The centres were found to be almost exactly 3 in. and 5 in. below the level surface of the soil. As far as can be judged from working with the records, both elements have given a very satisfactory record of earth temperature.

Results of the Earnscleugh Observations

The results of analysing the temperature observations at Earnscleugh are given in Tables 1, 2, and 3. Table 1 contains the mean monthly maximum and mean monthly minimum soil temperatures recorded at depths of 3 in. and 5 in. respectively as well as monthly mean values of the soil temperature for each depth as calculated from the formula $\frac{1}{2}$ (max. + min.). For purposes of comparison the same quantities are also given for air temperature as measured at a height of 4 ft. above the ground in a standard (non-aspirated) Stevenson screen.

The outstanding features of these tables may be summarized as follows :—

A. *At a Depth 3 in. in the Soil (Table 1) :—*

(1) In the summer months the mean maximum soil temperatures are considerably higher than the mean maximum air temperatures. For example, in January the mean maximum soil temperature was 89° F., while the mean maximum air temperature reached only 77° F. In the winter months the mean maximum soil temperatures are rather lower than the corresponding mean maximum air temperatures. Thus in July mean maximum soil temperature was 35° F., while the mean maximum air temperature was 42° F.

(2) Mean maximum air temperatures and mean maximum soil temperatures become equal round about April and September.

(3) Mean minimum soil temperatures are consistently higher than mean minimum air temperatures, the difference being greater in summer than in winter. Thus in January this difference is about 10° F., while in July it reaches only 5° F.

B. *At a Depth of 5 in. in the Soil (Table 2.) :—*

(1) In midsummer there is very little difference between the mean maximum soil temperatures and the mean maximum air temperatures, but at other times of the year conditions are similar to those at the 3 in. depth in winter, in as much that the mean maximum soil temperatures are lower than the mean maximum air temperatures. This difference is greatest in midwinter, being then about 9° F.

(2) As was the case with the 3 in. depth, the mean minimum soil temperatures at the 5 in. depth are consistently higher than the mean minimum air temperatures, the difference being about 13° F. in January and about 6° F. in July.

Table 2 shows the extreme maximum and minimum soil temperatures recorded at the 3 in. and 5 in. depths, together with the respective maximum and minimum air temperatures for the same days as those on which the extreme maximum and minimum soil temperatures at these depths occurred. Where the same extreme maximum or minimum soil temperature was recorded on more than one day, the average of the corresponding maximum or minimum air temperatures has been taken. This table is very similar to the corresponding Table 1, the main differences being in the absolute magnitudes of the temperatures recorded. Thus the highest soil temperature during the period at the 3 in. depth was 102° F. on 3rd January, 1948 (the mean maximum for January is 89° F.), and at the 5 in. depth the highest value recorded was 86° F. on 5th January, 1948 (the mean maximum for January is 77° F.). Similarly, the lowest soil temperature recorded during the period at the 3 in. depth was 28° F. on 6th July, 1947 (the mean minimum for July is 31° F.), and at the 5 in. depth the lowest value recorded was 30° F. on 5th, 6th and 7th July, 1947 (the mean minimum for July is 32° F.). In January it appears that the soil temperature at the 3 in depth never falls below about 55° F., and at the 5 in depth it never falls below about 58° F. In July, however, no soil temperature in excess of 47° F. was recorded at the 3 in. depth, and no value in excess of 39° F. occurred at the 5 in. depth. Table 3 shows for every month the greatest, least, and mean diurnal ranges of soil temperatures observed at the depths of 3 in. and 5 in. respectively, together with the ratios of the mean diurnal ranges at these two depths. Extreme values are given only to the nearest half degree. For purposes of comparison the mean diurnal range of air temperature derived from seventeen years' observations in the screen at Alexandra (near Earnscleugh) is included in Table 3.

Discussion of the Earnscleugh Results

Assuming that heat is transferred in the soil in accordance with the normal theory of conduction, it is possible to use the above results to determine the diffusivity of the soil and thence to calculate its thermal conductivity. If K is the diffusivity, ρ the density and δ the specific heat of the soil, then the thermal conductivity is given by the quantity $K\rho\delta$. In this paper most attention is given to the determination of the quantity K.

Diffusivity of the Soil

The temperature of the surface of the soil will vary periodically with the altitude of the sun and may be regarded as the sum of several harmonics of rather rapidly decreasing amplitude. In these circumstances the normal theory of conduction of heat shows that each harmonic wave is transmitted downward with amplitude decreasing exponentially with the depth and is subject to a phase retardation proportional to the depth. Thus with increasing depth below the surface of the soil the harmonics of small amplitude will become negligible, and the temperature may be expressed more and more accurately by a simple sine curve. Assuming a simple sine curve, the quantity K can be computed from the equation $K = \dfrac{\pi(z_2 - z_1)^2}{T\left\{\log_e \dfrac{R_1}{R_2}\right\}^2}$ where R_1 and R_2 are the daily ranges at depths z_1 and z_2 below the surface, z_1 in our case being 3 in. and z_2 5 in.

Table 4 shows the result of such calculations for $z_1 - z_2 = 2$ in. and a range of values of the ratio $r = \dfrac{R_1}{R_2}$ that commonly occurs in practice.

From this table we can pass directly from the ratio of the ranges r at the two depths to the corresponding value of the diffusivity K :—

TABLE 4

r.	K. (C.G.S. Units).
2·0	.. 1·9 x 10^{-3}
2·1	.. 1·7
2·2	.. 1·5
2·3	.. 1·3
2·4	.. 1·2
2·5	.. 1·1
2·6	.. 1·0
2·7	.. 0·9
2·8	.. 0·9

Results from Earnscleugh show that the ratio of the mean daily ranges at the two depths was very nearly constant for each month of the period, the lowest value of r being 2·2 and the highest being 2·6. The average value of r as found from the mean daily ranges for each month of this period is approximately 2·4, and from Table 4 this value corresponds to a value of K equal to approximately 1·2 x 10^{-3} C.G.S. units. This value seems abnormally low, and is, in fact, about one-quarter of that found by Johnson and Davies from a consideration of the ratio of the diurnal ranges observed at depths between 1 in. and 12 in. in grass covered chalky soil.

There is, however, an alternative method of determining the diffusivity of the soil—that is, by means of the change of phase undergone by the temperature wave with increasing depth. The most convenient way of measuring this phase-change in practice is to note the time-lag between the times of maximum temperature at two specified depths. If L is the lag in seconds, K is readily computed from the formula : $K = \frac{T(z_2 - z_1)^2}{4\pi \; L^2}$, where as before T is the period (twenty-four hours or 8·64 x 10^4 seconds), and z_1 and z_2 are the two depths.

For the case in which $z_1 - z_2 = 2''$ Table 5 is computed from the above formula and gives the calculated value of K for a range of values of L.

TABLE 5

Lag L (Hours).	K (C.G.S. Units).	Lag L (Hours).	K (C.G.S. Units).
1·3	8·1 x 10^{-3}	3·2	1·3 x 10^{-3}
1·4	7·0	3·3	1·3
1·5	6·1	3·4	1·2
1·6	5·3	3·5	1·1

Tabulation of a considerable number of cases giving the times of maximum temperature at the depths of 3 in. and 5 in. and also the corresponding lag between the two depths shows that although there is a certain variation among the times of maximum temperature at the two depths the lags are fairly consistent. The mean of all the observations gives the time of maximum at 5 in. as 16·4 hours local time, and the time of maximum at 3 in. as 14.9 hours local time. The average lag is thus 1·5 hours for a distance of 2 in. in the soil.

From Table 5 it will be seen that if the previously found estimate for the diffusivity is approximately correct, the lag between the 3 in. depth and the 5 in. depth should be in the vicinity of 3·3 hours. It thus appears that heat is conducted downwards between the 3 in. and 5 in. levels at a faster rate than is consistent with the normal theory of conduction of heat in a solid in as much as the methods depending respectively on the amount of lag and the decrease of daily range between the two levels do not, in this case, yield concordant results. The lag of 1·5 hours corresponds to a value of 6·1 x 10^{-3} C.G.S. units, which is in reasonable agreement with the diffusivity found by Johnson and Davies for chalky soil on the Salisbury Plain. Johnson and Davies found no disagreement between the results of the lag method and the ratio method, but results similar to those found in this paper have been emphasized by Wright, who attributed the discrepancy to the presence in the top layers of the soil of numerous grass-roots which somehow interfere with the normal process of conduction.

PART II—OBSERVATIONS IN OTHER LOCALITIES

Wairenga-o-kuri, Gisborne District

In view of the anomalous transfer of heat that has been found to take place in the surface layers of the soil at Earnscleugh it was thought worthwhile to make a brief examination of earth thermograph records from other parts of New Zealand in order to see if any similar phenomenon occurred. The most convenient set of records is that from Wairenga-o-kuri, in the Gisborne district, which give continuous records of temperature at 4 in. and 8 in. below the surface of bare soil. The results obtained at Wairenga-o-kuri for a period of observations during October, 1947, are shown in the self-explanatory Table 6.

This table shows that the mean lag is about 3·5 hours, and for a difference of depth of 4 in. we find that this corresponds to an average value of 4·5 x 10^{-3} C.G.S. units for K. The mean ratio of the ranges observed at 4 in. and 8 in. depth is 2·56, which corresponds to a value of K equal to 4·3 x 10^{-3}. Thus in the soil at Wairenga-o-kuri the values of K obtained by both the ratio method and the lag method are perfectly consistent and lead to a very reasonable value for the diffusivity. Here there is no question of anomalous transfer of heat in the soil. Records from other parts of New Zealand have also been examined and tend to show that the transfer of heat is, in general, normal.

TABLE 1

	3 in. Earth.			5 in. Earth.			Screen.		
	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.
1948									
January ..	89·2	62·5	75·8	77·5	66·0	71·7	77·0	52·9	65·0
February ..	84·0	59·3	71·6	73·3	63·5	68·4	75·7	46·7	61·2
March ..	74·7	53·8	64·2	66·6	56·9	61·7	69·7	45·6	57·6
April ..	60·9	45·6	53·2	54·6	48·2	51·4	61·9	37·7	49·8
1947									
May	49·1	38·6	43·8	45·1	40·5	42·8	55·5	32·7	44·1
June ..	39·2	33·2	36·2	36·5	34·2	35·3	44·6	29·0	36·8
July	35·0	31·5	33·2	32·7	31·9	32·3	42·1	26·3	34·2
August ..	47·0	35·0	41·0	41·0	36·5	38·6	54·0	31·4	42·7
September ..	58·1	39·8	48·9	49·9	42·2	46·0	60·4	36·0	48·2
October ..	66·1	47·2	56·6	57·8	49·3	53·5	61·5	42·1	51·8
November ..	82·3	55·4	68·8	70·0	58·6	64·3	67·7	45·7	56·7
December ..	83·1	59·5	71·3	72·4	61·6	66·5	73·2	49·1	61·2

TABLE 2

—	3 in. Earth.				5 in. Earth.			
	Extreme Maximum.	Extreme Minimum.	Correlated Air Maximum.	Correlated Air Minimum.	Extreme Maximum.	Extreme Minimum.	Correlated Air Maximum.	Correlated Air Minimum.
1948								
January ..	102	55	92	41	86	58	93	42
February ..	97	47	85	39	81	54	85	39
March ..	90	48	79	39	76	51	78	39
April ..	72	38	67	27	63	42	70	27
1947								
May ..	61	30	66	21	54	33	68	21
June ..	47	30	42	21	41	33	47	21
July ..	47	29	41	21	39	30	54	20
August ..	54	32	56	29	46	32	56	29
September ..	70	34	70	32	58	37	69	32
October ..	79	39	62	32	67	42	70	32
November ..	97	42	82	27	78	48	80	27
December ..	97	45	81	36	81	44	80	36

TABLE 3

—	3 in. Earth.			5 in. Earth.			Ratio of Mean Ranges	Alexandra Screen Daily Range.
	Maximum Daily Range	Minimum Daily Range.	Mean Daily Range.	Maximum Daily Range.	Minimum Daily Range.	Mean Daily Range.		
1948								
January ..	43·0	4·0	26·7	19·0	1·0	11·5	2·3	21·6
February ..	39·0	5·0	24·7	16·0	1·0	9·8	2·5	22·0
March ..	30·0	8·0	20·9	15·5	2·5	9·7	2·2	22·7
April ..	22·5	6·0	15·3	10·0	2·0	6·4	2·4	20·6
1947								
May ..	15·5	1·5	10·5	8·0	0·0	4·6	2·3	18·8
June ..	15·5	0·0	6·0	5·0	0·0	2·3	2·6	16·3
July ..	15·0	0·0	3·5	6·5	0·0	0·8	4·4	16·2
August ..	16·5	5·0	12·0	7·0	2·5	4·7	2·5	19·9
September ..	30·0	2·5	18·3	14·0	0·5	7·7	2·4	20·9
October ..	32·0	4·5	18·9	15·0	1·5	8·5	2·2	22·1
November ..	42·5	5·0	26·9	19·0	1·5	11·4	2·4	21·7
December ..	36·5	3·5	23·6	21·0	1·0	9·8	2·4	21·4

TABLE 6

Oct., 1948.	1.	8.	9.	10.	19.	20.	21.	22.	23.	24.	25.	26.	27.	28.	29.	30.	Mean.
R 4 in. ..	8·3	7·4	6·2	9·2	..	5·4	7·5	7·0	4·4	8·3	9·7	8·2	9·0	14·1	11·6	9·2	..
R 8 in. ..	3·6	2·8	2·3	3·9	..	2·0	2·8	2·8	1·6	3·0	3·6	3·0	4·0	5·6	4·9	3·8	..
r	2·3	2·6	2·7	2·4	..	2·7	2·7	2·5	2·7	2·8	2·7	2·7	2·3	2·5	2·4	2·4	2·56
T, Max. 4 in.	17·3	16·8	17·3	17·3	17·5	16·5	17·0	17·0	16·5	16·5	17·0	17·5	16·5	17·0	17·0	18·0	17·0 hr.
T, Max. 8 in.	20·2	20·1	20·2	21·6	20·8	19·9	20·3	21·2	19·7	19·8	20·3	20·8	20·1	20·5	21·0	22·3	20·5 hr.
Lag ..	2·9	3·3	2·9	4·3	3·3	3·4	3·3	4·2	3·2	3·3	3·3	3·3	3·6	3·5	4·0	4·3	3·5 hr.

Discussion

In reply to questions regarding the inconsistencies obtained by the two distinct methods of approach Mr. Hutchings said that at present he could offer no explanation for the inconsistent results obtained at Earnscleugh, but it was suggested that the usual Fourier analysis of the process of heat conduction should be modified to include representation by two independent parameters instead of one.

Mr. Priestley pointed out that Mr. Swinbank, of C.S.I.R., Australia, had made some very detailed experiments on soil conductivity and found that conditions were far more complicated than had hitherto been supposed.

In offering a possible explanation of the discrepancy in K values found by Mr. Hutchings, Mr. Priestley described an experiment by Mr. W. C. Swinbank to determine directly the thermal conductivity of soil. A note on this experiment has just been published (*Q.J. Roy. Met. Soc.*, 74, 321-322, July-Oct., 1948, p. 409). It appears that the temperature behaviour of soil which is not waterlogged cannot be described in terms of thermal conductivity alone, but a satisfactory explanation must take into account the movement of water vapour and the heat quantities involved in evaporation and condensation in soil interstices. These quantities, though small, may yet involve sufficient latent heat to mask the transfer of sensible heat.

A MERIDIONAL AEROLOGICAL CROSS-SECTION IN THE SOUTH-WEST PACIFIC[1]

By F. Loewe and U. Radok, Department of Meteorology, University of Melbourne

Aerological information was until recently very restricted in the Southern Hemisphere, particularly with respect to the higher part of the troposphere and to the stratosphere. This has completely changed during the war ; but very little of the accumulated data has yet been published, and only part of a tentative cross-section through the South Atlantic has become known.

In this study 4,800 radiosonde flights from six coastal and three inland stations of eastern Australia have been used to draw for the summer and winter seasons vertical cross-sections of the average temperature roughly along the eastern coast of Australia. The sections have been extended northward through New Guinea to the Marianas in 15° N. All these data have been carefully scrutinized. South of Australia 100 flights from Macquarie Island, in 54° S, have been used, and for the antarctic latitudes the great number of observations (about 100 flights) collected in the course of the United States Task Force Operation "Highjump" in the summer 1946–47 have been utilized. The southernmost data (140 flights) are those from the station "Little America" on the Ross shelf ice in $78\frac{1}{2}$° S., for which some still unpublished data have been kindly supplied by Mr. A. Court. The temperature cross-sections contain isotherms at a distance of 5° c. ; they extend to a height of 16 km., or 10 miles.

In *summer* (Fig. 2) below 10 km. the highest temperatures are found in 15–20° S. Up to about 4 km. the continental Australian stations give markedly higher temperatures than the coast in the same latitude ; at higher levels the difference disappears. The continental influence is

---

[1] A more complete version will be published in *Journal of Meteorology*.

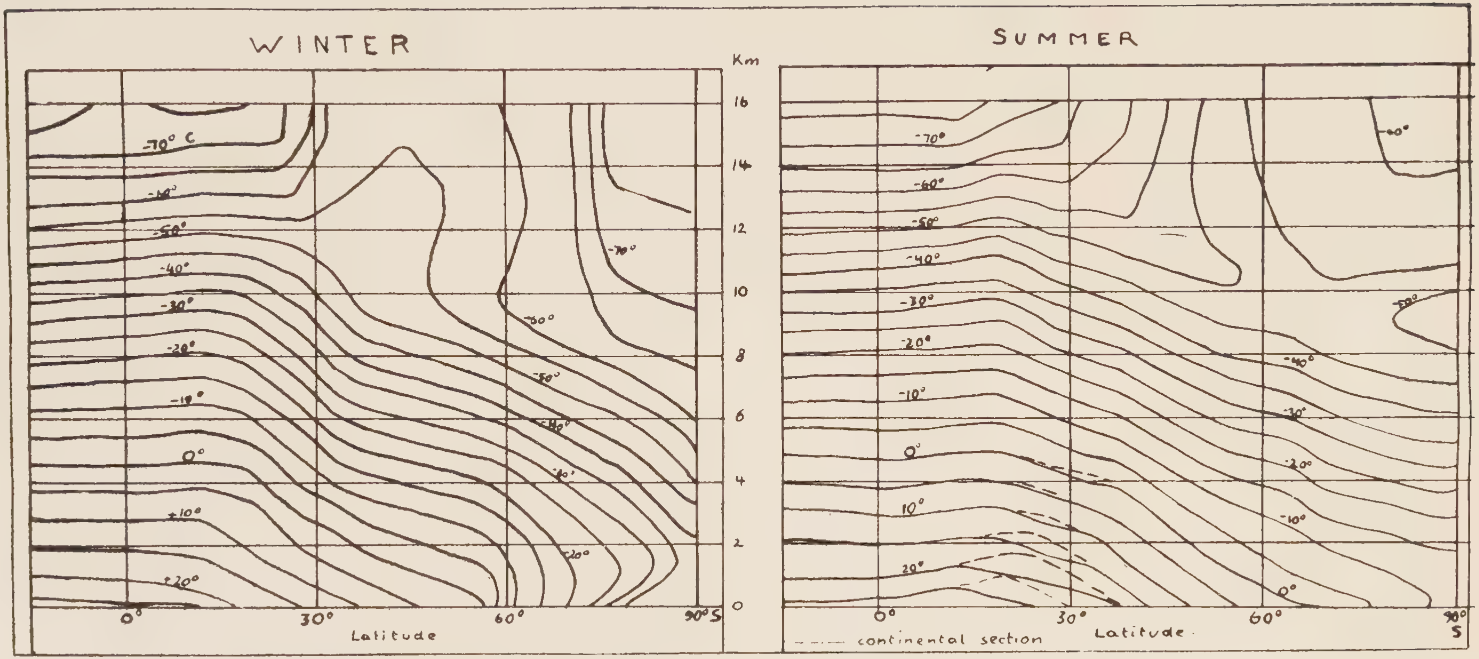


FIG. 1.

FIG. 2.

Temperatures, Southern Hemisphere.

thus much weaker than that of the more extended land masses of the Northern Hemisphere, where, for instance, the temperatures over the Sahara are higher and their difference against those of the Atlantic Ocean is larger than in Australia.

The coolness of the southern summer in higher latitudes is the most marked difference between the surface temperatures in the Northern and Southern Hemisphere. Beyond 40° of latitude the southern atmosphere is now found to be not only near the ground, but to a height of 8 km. 8–10° C. colder than the same latitudes in the Northern Hemisphere. This difference indicates the influence of the different distribution of land and sea upon the heat content of the bulk of the troposphere, but is probably mainly caused by the higher cloudiness and albedo of the Southern Hemisphere.

In *winter* (Fig. 1) the coldness of the antarctic stratosphere and the gradual obliteration of the tropopause towards the end of winter are the most marked features of the temperature distribution. At a level of 16 km. the average winter temperature in 78° S. is likely to fall to —80° C. A strong fall of temperature in the stratosphere in winter is found in the North Polar regions, too; but the average temperature remains still about 10° higher than above the Antarctic. Another interesting fact revealed by the temperature cross-section for the winter is the strong decrease of temperature in the troposphere between 20° and 40° S. A similar large temperature gradient is found in the Northern Hemisphere in slightly higher latitudes on the eastern sides of the North American and Eurasian Continents. This makes it somewhat doubtful whether this temperature gradient is in the south a feature that is characteristic of the whole hemisphere or whether is applies only to the longitude of the cross-section.

The stratosphere has in winter the highest average temperature in 40–50° S., whilst the temperature is lower towards the Pole as well as towards the Equator. Such a temperature maximum appears in the north, too, but it is more marked in the Southern Hemisphere.

With regard to the tropopause, Fig. 3 shows its average height in the southern cross-section and the average for the Northern Hemisphere. The observations suggest a discontinuity in the tropopause around 35° latitude which corresponds to one recently established in the Northern Hemisphere. A study of the frequency distribution of tropopause heights confirms the reality of this break. In *summer* the height of the southern tropopause beyond 40° S, is very similar to that of the northern tropopause in winter. Neither our cross-section nor the formerly mentioned data from the South Atlantic Ocean corroborate the claim for an extremely low position of the tropopause in the region of Kerguelen Island (lat. 50° S.).

In *winter* the height of the tropopause south of 30° S. is somewhat lower than in the Northern Hemisphere. The almost identical height at Melbourne (38° S.) and Macquarie Island (54° S.) appears well substantiated. Data from Little America give in winter a height of the tropopause of between 8 and $8\frac{1}{2}$ km., almost the same as in summer; this small difference between summer and winter appears at some places in high northern latitudes, too. The heights of the principal isobaric surfaces show above 3 km. the disappearance of the subtropical high-pressure belt. In *Summer* (Fig. 5) the slope of the isobars is steepest near the 300 mb. level. The inclination of the isobars is greater than in the Northern Hemisphere.

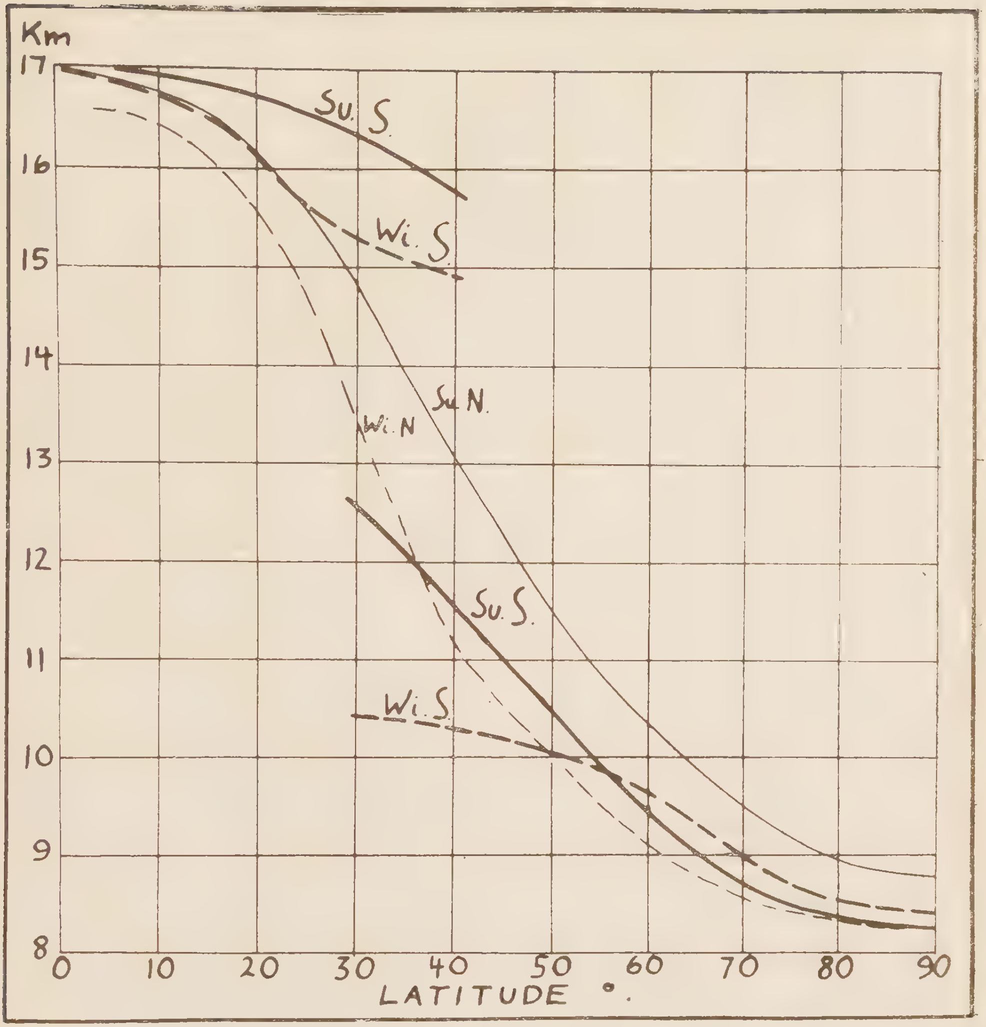


Fig. 3.

In *winter* (Fig. 4) the inclination of the higher isobars is very strong and increases upwards beyond the 150 mb. level. But the difference beween the southern section and the average conditions in the northern hemisphere is probably smaller than in summer.

Outside the equatorial regions the direction and speed of the wind in the free atmosphere is determined by the equilibrium of the Coriolis force and the pressure force. This fact allows the use of the meridional inclination of the isobaric surfaces to find the component of the wind along the circle of latitude—*i.e.*, the so-called "zonal" component of the general circulation. It must not be overlooked that the zonal wind component as computed from the average distribution of pressure gives a rather imperfect picture of the actual wind conditions since the meridional components of the motion are neglected and components towards

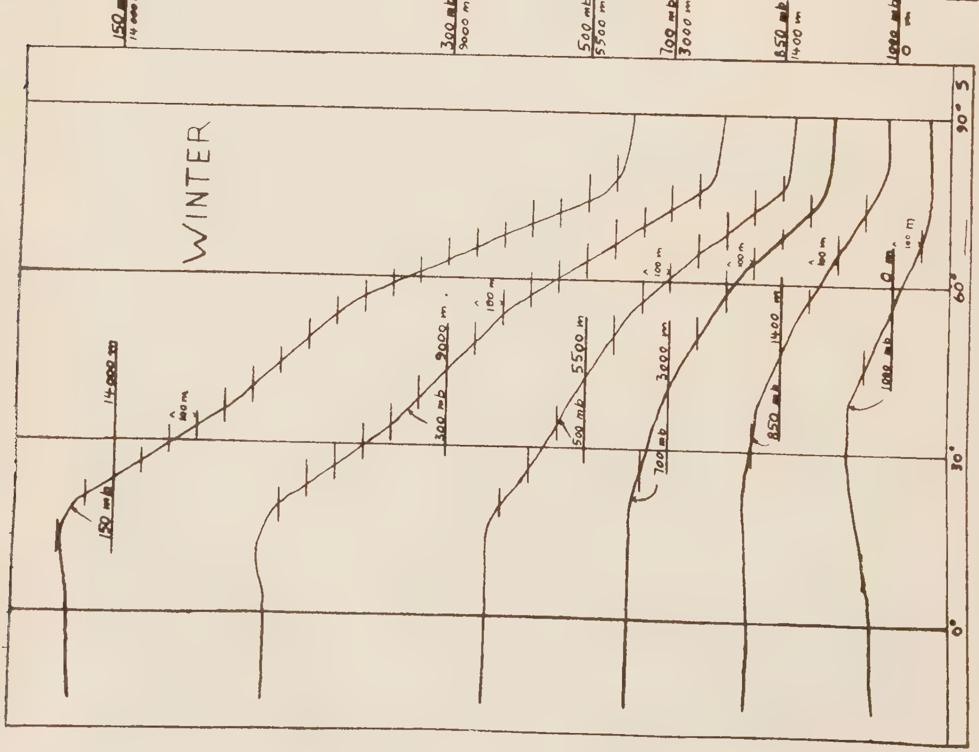

WINTER
150 mb
14000 m
100 m
300 mb
9000 m
500 mb
5500 m
700 mb
3000 m
850 mb
1400 m
1000 mb
0 m
0°
30°
60°
90° S
150 mb 14000 m
300 mb 9000 m
500 mb 5500 m
700 mb 3000 m
850 mb 1400 m
1000 mb 0 m

FIG. 4.

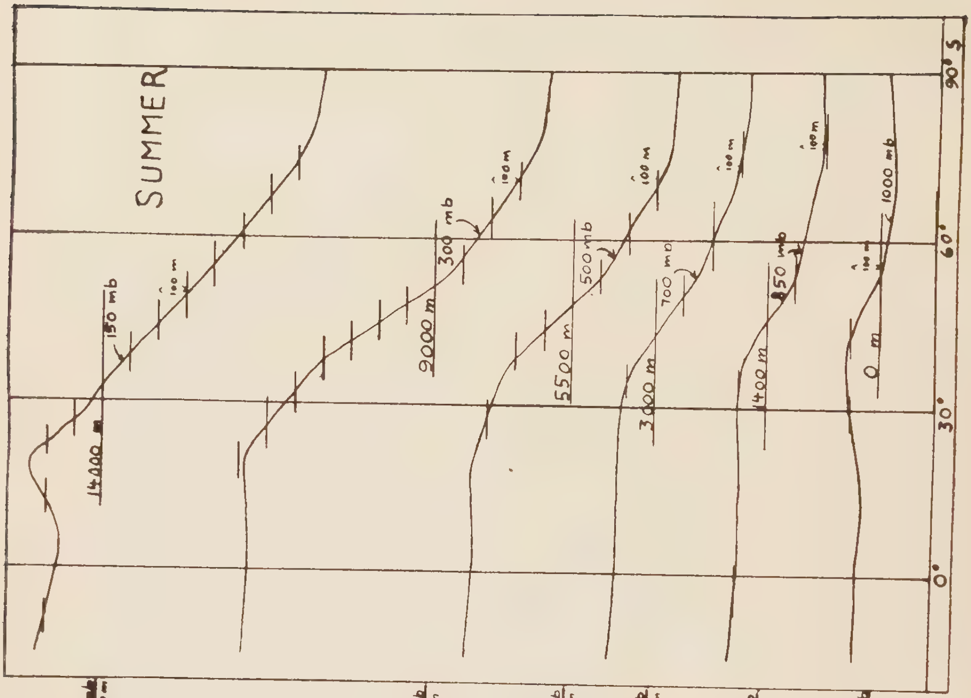

SUMMER
150 mb
14000 m
100 m
300 mb
9000 m
500 mb
5500 m
700 mb
3000 m
850 mb
1400 m
1000 mb
0 m
0°
30°
60°
90° S

FIG. 5.

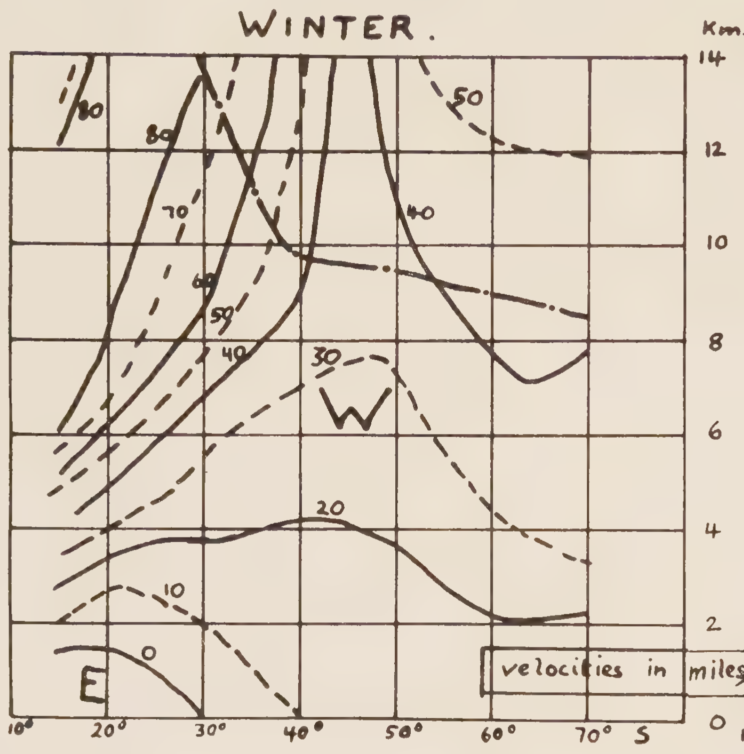

WINTER.
Km.
14
12
10
8
6
4
2
0
80
80
70
60
50
40
40
50
30
W
20
10
0
E
10°
20°
30°
40°
50°
60°
70° S
velocities in miles/hour

FIG. 6.

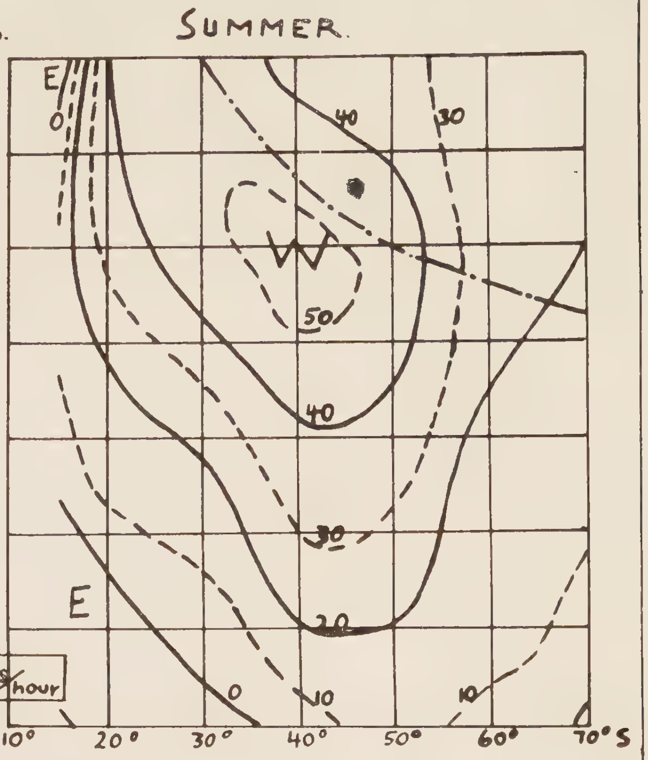

SUMMER.
E
0
40
30
W
50
40
30
20
E
0
10
10
10°
20°
30°
40°
50°
60°
70° S

FIG 7.

the east and west partly cancel each other. These restrictions are, however, probably less important in the Southern Hemisphere, where in the higher latitudes the actual flow is likely to be more purely from west to east than in the Northern Hemisphere. Figures 6 and 7 give the average zonal motion of the atmosphere as computed from the slope of the isobaric surfaces.

In *summer* (Fig. 7), in accordance with the stronger inclination of the isobaric surfaces, the zonal wind component is generally stronger in the Southern than in the Northern Hemisphere. At the 5 km. level, for instance, in temperate latitudes between 35 and 65° the zonal component in the south is nearly twice that of the north.

Just below the tropopause a maximum of the zonal wind component exists as in the Northern Hemisphere.

In *winter* (Fig. 6) the zonal wind velocities of the Southern Hemisphere are only slightly bigger than in summer. The small seasonal difference in the intensity of the circulation which characterises the surface layers in the higher latitudes of the Southern Hemisphere is found to extend through the whole troposphere. A remarkable feature of the southern cross-section is a minimum of the zonal wind component near 50° S. at the levels above 3 km. As a whole the intensity of the zonal circulation in our section through the Southern Hemisphere does not differ much from the average conditions in the Northern Hemisphere. Here again the more fundamental difference between the Northern and the Southern Hemisphere exists in summer rather than in winter.

A MERIDIONAL ATMOSPHERIC CROSS-SECTION FOR AN OCEANIC REGION

By J. W. Hutchings, New Zealand Meteorological Service

1. Introduction

At the present time meteorology does not have a generally accepted and adequate theory of the general circulation of the atmosphere. To some extent this is due to the lack of suitable theoretical tools, but it is at least as much due to the paucity of observational data over large areas of the globe. The lack of observational material is especially striking in the Southern Hemisphere—particularly in the oceanic portions—from which, until very recently, almost no free air observations were available. The aim of this preliminary paper is to bring forward some of the upper air observations that were made in the Pacific region during World War II, and to set them in relation to the upper air data available from stations in New Zealand. In order to present a more complete picture of the southern circulation some rather scanty Antarctic data are also included.

2. Observational Material

The following is a brief description of the observational material used in this study. All the temperature data used were obtained by standard Frieze radio-sonde equipment and were evaluated in the standard manner as prescribed in U.S.W.B. Circular P. While working with the records it was noticed that daylight flights almost invariably yielded higher temperatures than flights made in darkness, the difference being of the order of 3° c. It would seem that the greater part of this difference is due to insolational heating of the instrument and that records from daylight flights are consequently unreliable. In this study only night-time flights have been considered except for the inclusion of a few high-level temperatures from daylight ascents when the daylight and night-time flights at the higher levels showed close agreement. These flights were included to make the high level averages more reliable. The observation stations used in this cross-section were selected so as to lie as far as possible along one meridian, thus trying to avoid the more serious difficulties of interpretation which have arisen with most of the so-called "meridional" cross-sections that have been presented up to date. It will be seen that most of the stations lie within 5° of meridian 170° E., the exceptions being Bougainville (15° W. of 170° E.) and Guadalcanal (10° W. of 170° E.). However, it is not thought likely that this slight deviation from meridian 170° E. will give rise to any fundamental differences in the final picture of the temperature field along this meridian. Again, it will be evident that the cross-section lies in a purely oceanic region and should be relatively free from large-scale effects of continentality. One defect of this section, however, is the scarcity of data south of latitude 46° S., but this seems unavoidable at present. In the future it is possible that the aerological observations made recently by the U.S. Navy far to the south of New Zealand can be used to complete the cross-section in higher latitudes. The only data at present available is the rather scanty Antarctic temperature data published by A. Court in 1942(1).

The following table 1 shows the actual dates of the material used. It will be noticed that the months selected cluster closely round January or February for summer and July or August for the winter cross-section, but the actual data used frequently depend on the number of high level flights in each month's records.

TABLE 1

Station.	Summer.	Winter.
Wake Island (19° N.)		July, 1946.
Kwajalein Island (9° N.)		June, 1945 (100 and 80 mb. include a few daylight ascents).
Tarawa Island (1½° N.)		June, 1945 (100, 80, 60, 50, 40 mb. include a few comparable daylight ascents).
Bougainville Island (6° S.)	January, 1945	June, 1944.
Guadalcanal Island (9½° S.)	January, 1945	June, 1945 (150 mb. and higher include temperatures for April, 1943).
Santo (15½° S.)	November, 1945	July, 1945.
Vila (18° S.)	February, 1944 (13 km. and above include also March, 1944)	July, 1944 (13 km. include June and August, 1944 ; 16 km. and higher include May-September, 1944).
Noumea (22° S.)	February, 1944, 1945 (300, 200, 100 mb. include January, 1944, 1945)	August, 1943, 1944 (300, 200, 100 mb. include July, 1943, 1944).
Norfolk (29° S.)	February, 1944–1946	September, 1943 ; August, 1944, 1945.
Auckland (37° S.)	February, 1944–1948	August, 1943–1948.
Hokitika (43° S.)	February, 1945, 1947, 1948	August, 1945–1948.
Taieri (46° S.)	February, 1944, 1945	August, 1944, 1945.
Little America (78° S.)	14 observations, January, 1940	15 observations, September, 1940.

3. TREATMENT OF DATA

As the volume of data made the plotting of every flight impracticable the following method of treatment was adopted. The temperature and humidity were extracted at each standard isobaric surface (following the general plan presented on the W.B.A.N. adiabatic charts), and the average virtual temperatures at these levels were computed. The mean values for each station were then replotted on an adiabatic chart, after which the heights of the standard surfaces were computed and a pressure height curve drawn. The temperature values at standard geopotential were then read directly from the pressure height curve. In some cases only material coded in the 1943 Radiosonde Code was available, and in this case pressure temperature and humidity at the standard heights were averaged and the same procedure used.

This method of treatment of the data can be justified, both theoretically and practically, but a practical test is more likely to be convincing. This is shown in Table 2, which gives the heights of the standard isobaric surfaces at Norfolk Island as computed by the above method (A) and also by the more usual method of averaging the heights of the pressure surfaces as computed from each flight (B). The data are for February, 1944–1946.

TABLE 2

Pressure Surface, Mb.	Height (A): Dynamic Metres.	Height (B): Dynamic Metres.
1,000	117	117
900	1,001	1,000
800	1,970	1,969
700	3,053	3,053
600	4,276	4,277
500	5,681	5,682
400	7,334	7,336
300	9,358	9,359
200	12,016	12,015

Where possible data for the height of the tropopause were obtained by both methods, and good agreement was obtained as long as sufficient observations were available to yield reasonably reliable means.

4. The temperature cross-sections are shown in Figs. 1 and 2 and show the principal features common to all such diagrams. There is no need to describe these well-known features here, but attention may be directed to a few details that are not generally recognized.

Although the mean tropopause is drawn as a continuous line it is very probable that there are two tropopauses—tropical and polar—and that there is a discontinuity at a certain latitude. This is clearly seen in the mean sounding for Auckland (lat. 38° S.) in winter, where both tropopauses appear with sufficient regularity to appear in the mean temperature distribution.

Another fact that has not hitherto been sufficiently emphasized is that in the higher parts of the troposphere there exists in sub-tropical and tropical latitudes a reversed temperature gradient in which the isothermal surfaces slope upward from the Equator towards higher latitudes. Willett(2) has described a similar effect in the North American region in summer as being due to the heating effect of the American Continent, but such an explanation cannot be applied to a purely oceanic region, and the explanation must therefore be considered doubtful.

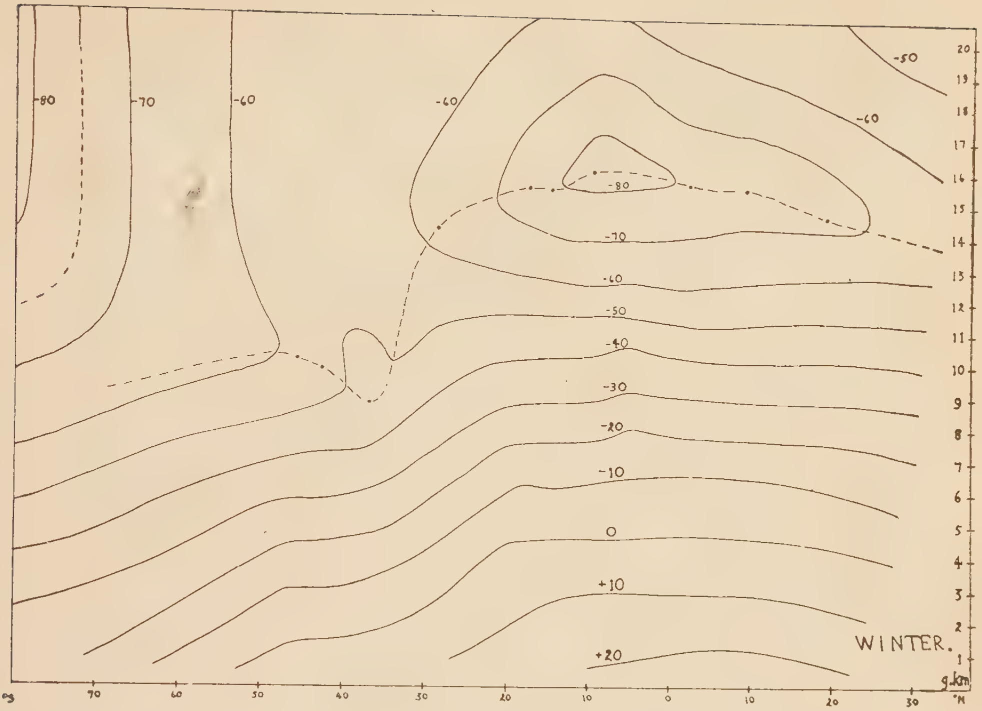

-80
-70
-60
-60
-50
-60
-80
-70
-60
-50
-40
-30
-20
-10
0
+10
+20
WINTER.
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
g.km
°S
70
60
50
40
30
20
10
0
10
20
30
°N

FIG. 1.

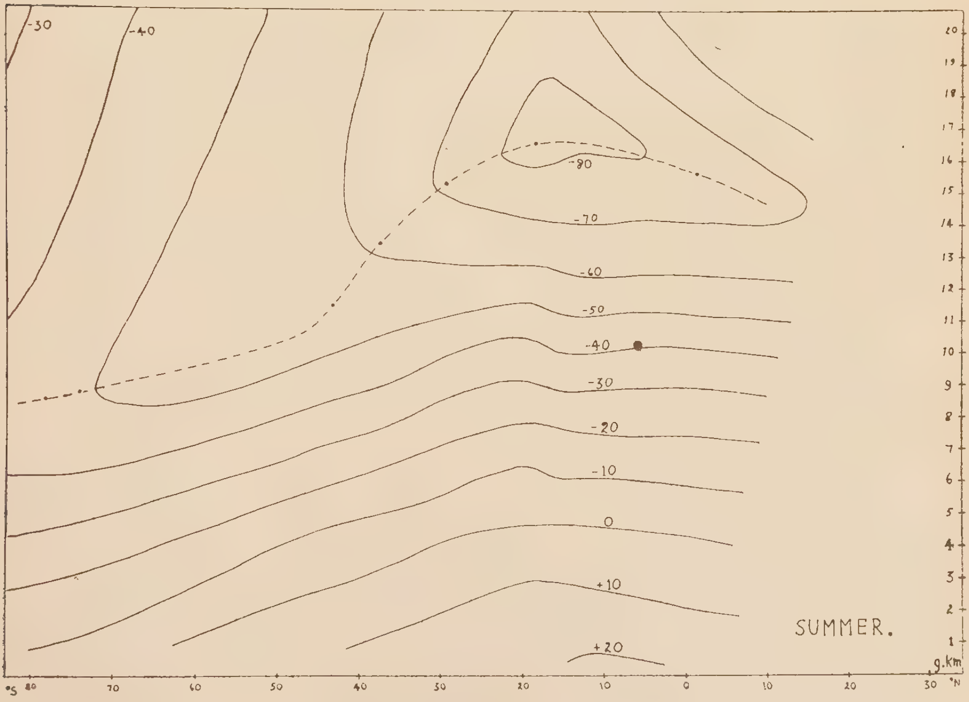

-30
-40
-80
-70
-60
-50
-40
-30
-20
-10
0
+10
+20
SUMMER.
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
g.km
°S
80
70
60
50
40
30
20
10
0
10
20
30
°N

FIG. 2.

The highest part of the tropopause shows a marked oscillation in position, according to the season of the year, but even in the winter season it seems to lie in the Southern Hemisphere. This marked asymmetry would seem to be a peculiarity of this region and is probably not a general feature of the southern circulation.

It is of interest also to note that in certain sub-tropical latitudes temperatures in the upper part of the troposphere are warmer in winter than in summer.

Regarding the seasonal variation of the tropopause it would seem that in this region the tropical tropopause is higher in summer than in winter as is also the polar tropopause. Variations of the latter tropopause from winter to summer, however, seem to be somewhat greater. This variation of the tropical tropopause is contrary to the variation given by Willett(2) for the North American region.

However, the conclusions reached in this paper obviously need confirmation by the examination of a larger number of records. This task is now being undertaken, and the results will be presented as soon as possible.

REFERENCES

(1) COURT, A.: *Bulletin of American Meteorological Society*, May, 1942.
(2) WILLETT, H. C.: *Descriptive Meteorology*, 1944.

HEAVY RAINS IN HAWAII AS RELATED TO IMPORTATION OF COLD AIR ALOFT

By R. H. SIMPSON, U.S. Weather Bureau, Honolulu

[*Abstract*]

Analyses of time cross-sections for Honolulu soundings are considered in relation to flow patterns over the Eastern Pacific during periods of heavy rain in Hawaii. It is shown that flow patterns become more clearly related to rain occurrences when analyses are extended into the middle and upper troposphere. This is supported by recent studies of Mordy and Leopold which show conditions at 300 mbs. to be most significantly correlated with the occurrence of general rain. Outbreaks of rain are preceded by importations of cold air aloft which may reach the Hawaiian area either from the north, upon arrival of a polar trough, or from the east in connection with easterly waves. Heaviest rains occur with the simultaneous arrival of cold air from both sources.

When cold air aloft streams southward into the tropics and becomes detached from its source, it tends to disappear rapidly through subsidence, but may occasionally collect in a broad pool and persist. It is noted that the latter condition frequently seems to foreshadow the development and westward movement of an easterly wave.

WEATHER OBSERVATIONS IN THE ANTARCTIC SEAS

By M. TAMURA and J. SUGIURA, Central Meteorological Observatory, Japan

THE authors were engaged in weather observations in the Antarctic Seas on board the Japanese whaling ship "Hashidate Maru," of 10,000 ton, from 4th December, 1947, to 8th March, 1948. The operation field of the ship covered sea area ranging from S. 63° 06′ to S. 75° 41′ and from E. 148° 04′ to W. 172° 08′. The results of weather observations will be summarized below.

PRESSURE

(1) Maximum, minimum, and average pressure observed aboard throughout the whaling season were 1,011·7 mb., 951·4 mb., and 985 mb. respectively.

Maximum change of pressure in three hours was 6·9 mb. when going up and 7·7 mb. when down. Generally speaking the amount of pressure change in three hours was least in December and increased toward March. However, geographically, it was smaller in the Ross Sea than in the sea area north of Balleny Islands.

TEMPERATURE

(2) Maximum and minimum of temperature observed on board the ship throughout the period were 2·7° C. and —6·2° C. respectively. Mean of the daily amplitude of temperature was 1·5° C. to 2·0° C. Mean temperature in the same period was lower by 1·5° C. in the Ross Sea than in the sea area east of the Balleny Islands.

Average humidity was different according to locations, generally ranging between 85-90 per cent. But the humidity in the Ross Sea was around 75 per cent., showing comparatively lower values than in the other sea areas.

Maximum and minimum sea surface temperatures, throughout the period were 1·1° C. and —1·6° C. respectively.

WINDS

(3) Westerlies prevailed in the northern territory of the whaling ground, ranging from S. 63°–S. 65°. No conspicuous difference between the frequencies of easterlies and westerlies in the sea area east of Balleny Islands was observed, and easterlies prevailed in the Ross Sea.

The biggest frequency of wind force over the period was four. The smallest frequency of strong winds was experienced in December and increased toward March. Four observations of strong winds exceeding 20 m/sec. were taken in the whaling ground. The occurrence date of each and its accompanying weather conditions were as follows :—

Month.	Date.	Time.	Latitude.	Longitude.	Press.	Wind.		Sky Condition.	Tendency of Pressure.
						Direction.	Speed.		
			° ′	° ′	mb.		m/sec.		
Jan. ..	4	19	S. 64 45	E. 153 33	991·2	W.	20·8	Overcast	Ascending.
Feb. ..	10	21	S. 70 02	E. 179 00	977·1	S.S.E.	20·3	,,	,,
Feb. ..	29	08	S. 67 56	E. 172 42	974·4	S.	21·2	Snow ..	,,
Mar. ..	3	12	S. 67 05	E. 166 29	951·4	S.	35·3	,, ..	Minimum.

Generally, pressure goes down in the winds from N.E. quarter, and goes up in the winds from S.W. quarter. Average of pressure changes in three hours, classified according to eight points of wind directions, is as follows :—

N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.
mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.
—0·61	—1·47	—0·77	—0·69	1·24	1·17	0·44	0·04

(4) Frequency of occurrence of sea fog, closely related to the whaling, is given below :—

Region (Lat./Long.).			Frequency of Fog Occurrence. Per Cent.
	° °	° °	
A	S. 64–66	E. 148–156	29·2
B	S. 63–66	E. 156–164	24·5
C	S. 65–70	E. 164–180	16·8
D	S. 70–75	E. 180–172	2·5

Above is the result obtained from the records taken aboard the whaling mother ship " Hashidate Maru," while the following is the result recorded aboard another whaling mother ship " Nisshin Maru."

	° °	° °	Per. Cent.
B′	S. 63–65	E. 158–163	22·3
C′	S. 66–68	E. 166–171	14·0
E	S. 66–68	E. 160–164	23·1

The most frequent fog occurrence was seen in the sea area covering S. 64°–65° and E. 148°–156° showing 30 per cent. And it was 23 per cent. in the sea area covering S. 63°–68° and E. 156°–163°, 15 per cent. in the east of the Balleny Islands, and about 2 per cent., the least, in the Ross Sea.

CLIMATE AND WEATHER OF JAPAN

By K. Takahashi, Central Meteorological Observatory, Japan

Climate and weather of Japan have been studied by the author, especially the synoptic aspects. Seasonal changes such as beginning and ending of summer are not continuous but discontinuous. For example, the temperature rises suddenly in the middle of July and falls suddenly in the middle of September. Such phenomena are found in normal annual change of air temperature as well as yearly annual change. This may be explained as follows. In the middle of July the summer monsoon begins and the frontal zone in front of Tm air crosses Japan towards the north while in the middle of September, the summer monsoon is over and the frontal zone re-crosses Japan towards the south. Rainy seasons of Japan, Baiu in June and typhoon rain in September, are accompanied by the passage of the frontal zone.

In Japan we found other rainy seasons, spring rain in March or April, and winter rain in November or December, though they are not as distinct as Baiu and typhoon rain. These rainy seasons occur with the passage of the polar frontal zone in front of Pc air masses coming from the continent as the winter monsoon. In the following table normal dates and standard deviations of the beginning and ending of every season and the synoptic characters of every season are shown.

Classification of Seasons in Japan

Season.	Weather Type.	Period.	Remarks.
Spring	High and low pass cyclicly, weather variable	Mar. 1 ± 16	Temperature rises suddenly after passage of travelling anticyclone.
Early summer	High belt forms, fair and mild	April 30 ± 8	Cyclic change of weather over.
Baiu	Tropical front forms south of Japan, rain	June 5 ± 10	Temperature falls, rainy season begins.
Summer	Southerly monsoon prevails, hot, fair weather, stable	July 18 ± 7	Temperature rises suddenly, sometimes accompanied by heavy rains.
Fall rain	Tm air mass replaced by Pc, raining	Sept. 11 ± 6	Temperature falls suddenly, sometimes accompanied by typhoons.
Fall	High and low pass cyclicly, weather changes cyclic	Oct. 10 ± 9	Rainy weather over continental high develops.
Early winter	Cold air mass comes to Japan, occasional showery precipitation	Nov. 20 ± 10	Winter type pressure pattern begins occasionally.
Winter	Northerly monsoon prevails cold and fair on Pacific coast, snowy on Japan sea coast, stable	Dec. 18 ± 5	Temperature falls suddenly after passage of cyclone.

In this table only an outline of the characters of every season are shown. Studying further we may have results which would be useful for long-range forecasting. The weather of Japan changes cyclically, as a whole, and we found three or four days and seven or nine days periodicity. The short period is caused by the passage of low, while the long period is caused by the outflow of highs from high latitudes. In summer and winter long periods predominate, and in spring and fall short periods predominate. We experience also thirty-five days periodicity. Japanese forecasters know that the modes of the weather changes have a yearly character, and similar weather situations appear very often in one year. This is proved statistically, and it is important for long-range forecasting.

ON SEA FOG OF ADVECTION TYPE OVER THE OYA SHIO

By Yoshihiko Takahashi, Central Meteorological Observatory, Japan

INTRODUCTION

In June–July fogs are frequently observed at sea along the Kuril Islands and the Pacific coasts of Hokkaido, when the warm and humid air from the south moves in over the Oya Shio.

The weather map in Fig. 1 shows a representative of the pressure distribution favourable to the occurrence of such fog, and Fig. 2 shows the distribution of the water temperature of sea surface averaged for the first ten days of August, 1941. This year the period of the predominance of the Oya Shio has been somewhat late.

As frequently as sea fog of advection type another type of fog, or frontal fog, occurs in the same season along the Kuril Islands and the Okhotsk coasts of Hokkaido, when the cold wind from the anticyclone over the Okhotsk Sea or the Bering Sea blows toward these districts.

The present paper, however, will be concerned with sea fogs of advection type only.

As to the causes of sea fogs it has been known only that as the warm and humid air moves over the colder water and is cooled from below so that its dew point is reached, fog will be produced. But from the physical point of view such a theory must confront many difficulties to explain quantitatively the properties of sea fogs. If the theory be correct, for example, sea fogs would not be much different in properties from

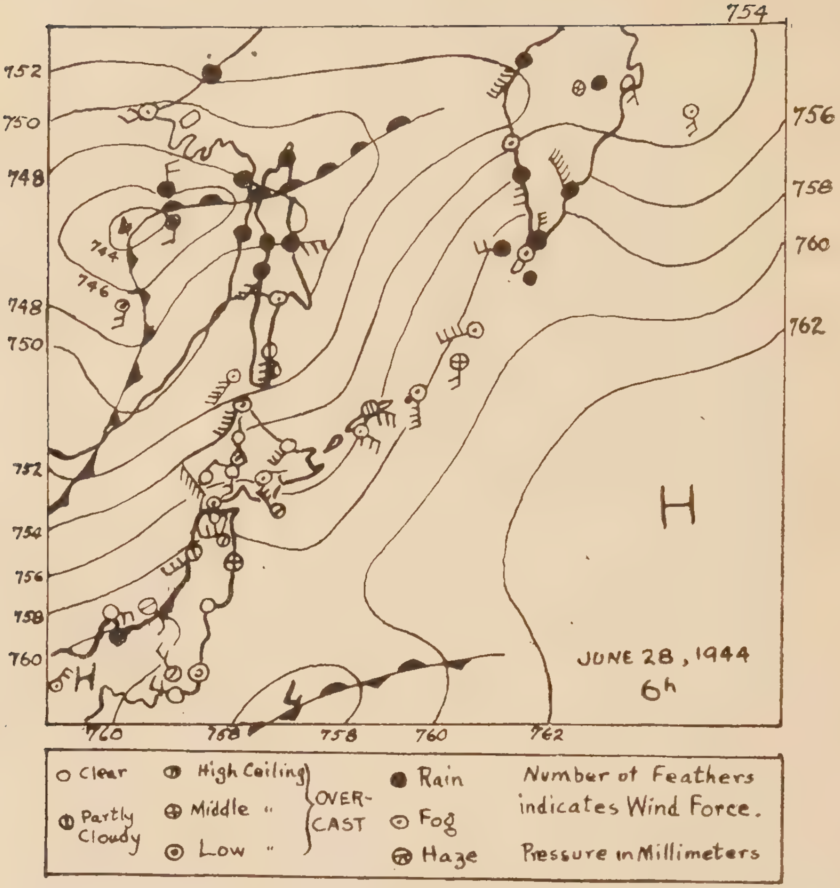

754
752
750
748
744
746
748
750
752
754
756
758
760
756
758
760
762
H
H
JUNE 28, 1944
6h
760
758
758
760
762
○ Clear
◑ Partly Cloudy
High Ceiling
Middle "
Low "
OVER-CAST
● Rain
Fog
Haze
Number of Feathers indicates Wind Force.
Pressure in Millimeters

FIG. 1.—Example of pressure distribution favourable to the occurrence of sea fogs of advection type at the sea along the Kuril Islands and the Pacific coasts of Hokkaido.

radiation fogs on land, because the latter are also caused directly by cooling of the air from below. But the observations do not show such identity at all.

Later Professor S. Petterssen has suggested the convection theory on the formation of sea fogs of advection type along the west coast of California. The theory is as follows: a stratus layer will be formed under the inversion by vertical mixing or convection in the air under the inversion, the base of the stratus layer coinciding with the condensation level of the surface air. When the condensation level comes down to the surface, or other fog-producing factors are present in the lower portion of the layer, the stratus builds down to the surface and forms a dense fog.

The theory of Professor Petterssen might be much better than the old theory to explain the nature of sea fogs, but the theory is still doubtful on account of the following reason: sea fogs are often accompanied by

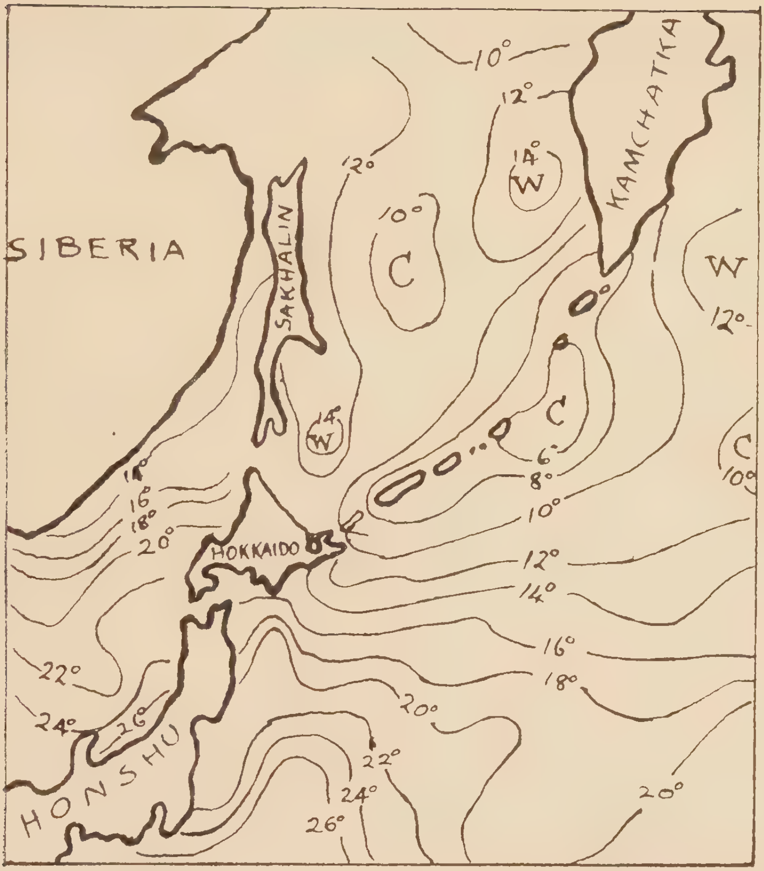


FIG. 2.—Sea-surface temperature in the first decade of August, 1941. This year predominance of the Oya Shio was late. (After daily information from ships to the Central Meteorological Observatory.)

mist or drizzle whose precipitation amounts to a not negligible quantity, so that there must be upward motion of the air as a whole in order to maintain the upward supply of water vapour and at the same time to suspend growing fog particles in the air. But such ascending motion of the air might not be expected by the convection theory.

The present author has suggested a new theory in 1944, the outline of which will be seen in the last part of this paper. This theory has proved the possibility that the warm air moving over the cold water might have ascending component of velocity.

The Nature of Sea Fog of Advection Type

On the basis of the observations of the present author and many other persons the nature of sea fog of advection type has been summarized below :—

(1) In June–July and sometimes in August sea fogs of advection type occur frequently in the regions immediately surrounding the Kuril Islands and along the Pacific coasts of Hokkaido, the densest

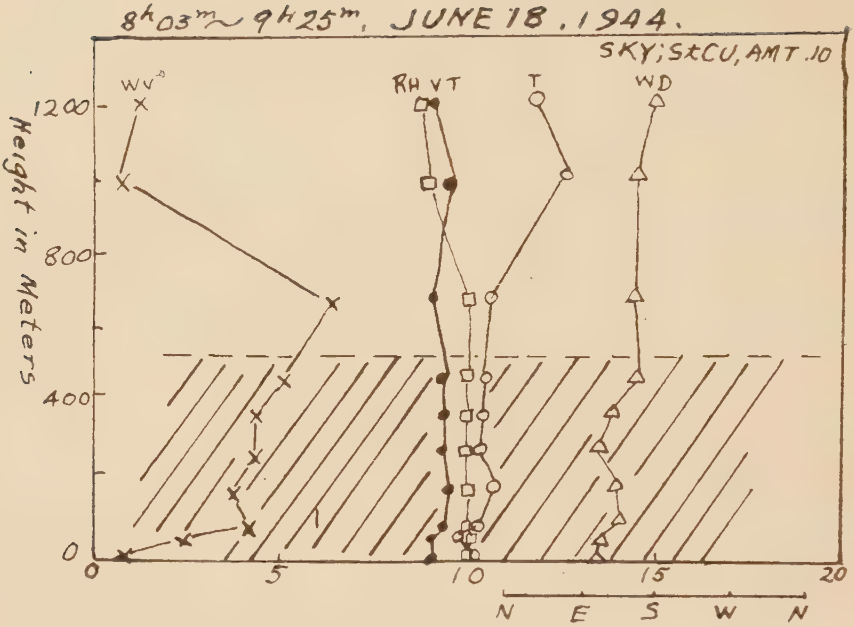


FIG. 3.

fogs being observed in the area to the south of Central Kuriles, where the Oya Shio is the most predominant. Usually sea fogs are carried in over coastal districts.

(2) Moderate breeze is most favourable to the formation of sea fogs, the direction of wind being between south-east and south-west.

(3) When the sky is overcast with low or middle cloud, fogs are in many cases dense and stable, and sometimes are maintained for several days or more throughout day and night.

(4) When the sky is cloudless or partly clouded, or covered with high cloud, fogs are usually thin in the daytime on account of receiving solar radiation and remain off the coast, but in the evening or at night they become dense and spread over coastal districts, where they dissolve the next day. Moreover, very thin fogs disappear entirely even at sea in the daytime and form again in the evening.

(5) Very often sea fog forms at some distance above sea-level. Such fog is usually called stratus, though there is no fundamental difference between them. In the opinion of the present author such stratus is but a special state of sea fog, and accordingly it is better to call it, for example, " high-base sea fog." But here " stratus " shall be still used according to the custom (see Fig. 4).

Sea fog changes frequently into stratus as it dissolves from below or its base rises above sea-level (mostly in daytime), and reversely stratus changes into fog as it builds down to sea-level or to the ground (mostly at night).

(6) Sometimes fog or stratus is formed of two or three different layers in piles. Such a single layer often changes into double or triple layer, and reversely double or triple layer often changes into single layer (see Figs. 5 and 6).

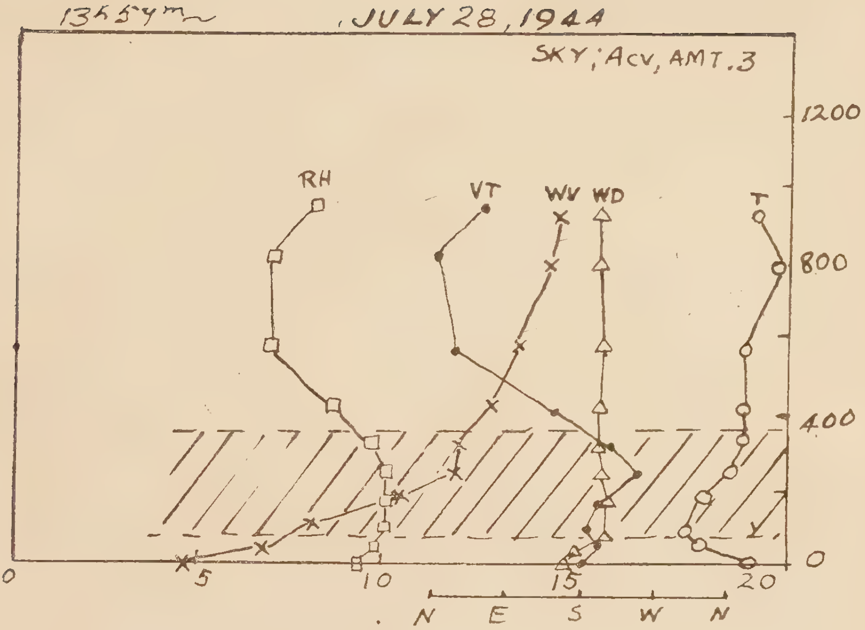


FIG. 4.

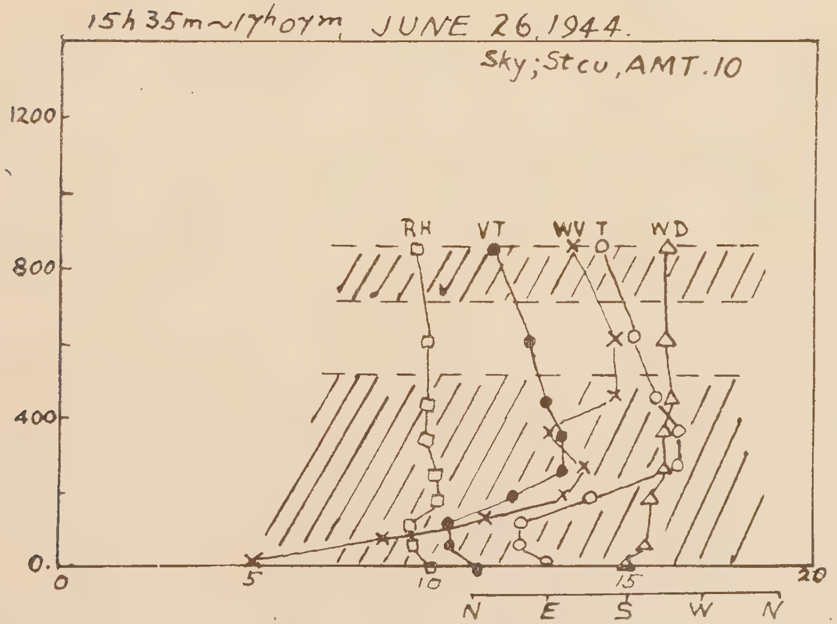


FIG. 5.—Example of sea fog of double layer and its vertical structure at Nemuro.

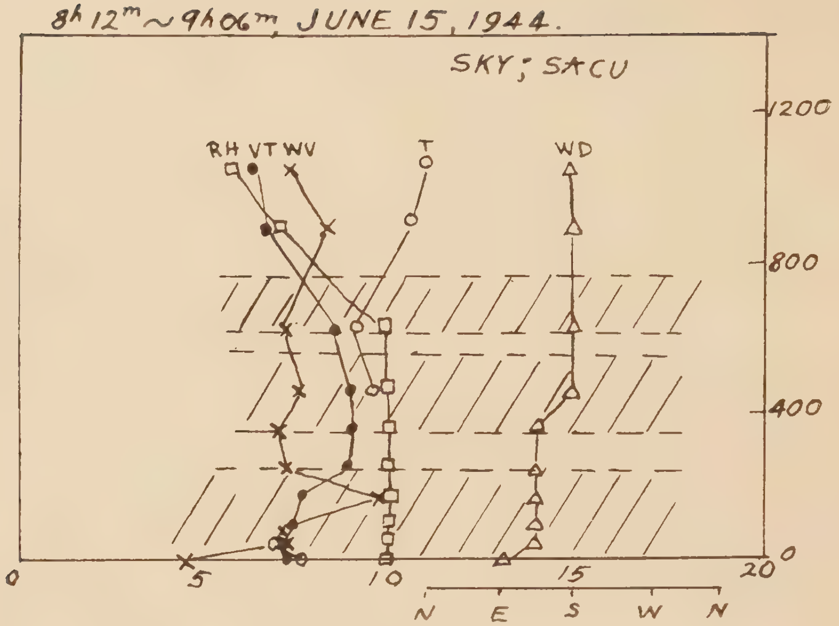


FIG. 6.—Example of sea fog of triple layer and its vertical structure at Nemuro.

Double and triple layers occur mostly in the case of double inversions, (see Fig. 6).

(7) The top of the inversion observed at Nemuro generally lies at a height of from 200 to 500 m., but in a few cases it reaches a height of nearly 1,000 m.

In the case of double inversions the top of the upper inversion is very high; therefore it might be considered that a very high single inversion forms through the disappearance of the lower inversion of a double inversion (see Fig. 3, where a trace of the lower inversion will be seen).

(8) Frequently mist or drizzle accompanies dense fog or stratus, precipitation amounting often to more than 2 mm. per hour, and the average size of drops being over 0·2 mm. in diameter.

(9) When fog or stratus is accompanied with drizzle, minute rain droplets are produced in the middle portion of the fog or stratus layer by the growth of fog particles, and they begin to fall from there. For the first some distance of falling they grow still larger with falling, but when the layer of unsaturated air is present below, falling drops diminish in size and in number on account of evaporation, and sometimes they cannot reach the surface (see Fig. 7).

(10) Wind direction remains almost constant with height, except in the first 100 metres, where wind is apt to turn westward on account of the frictional effect of the ground (see Figs. 3–5). But in some cases wind changes rapidly westward above the top of fog or stratus layer.

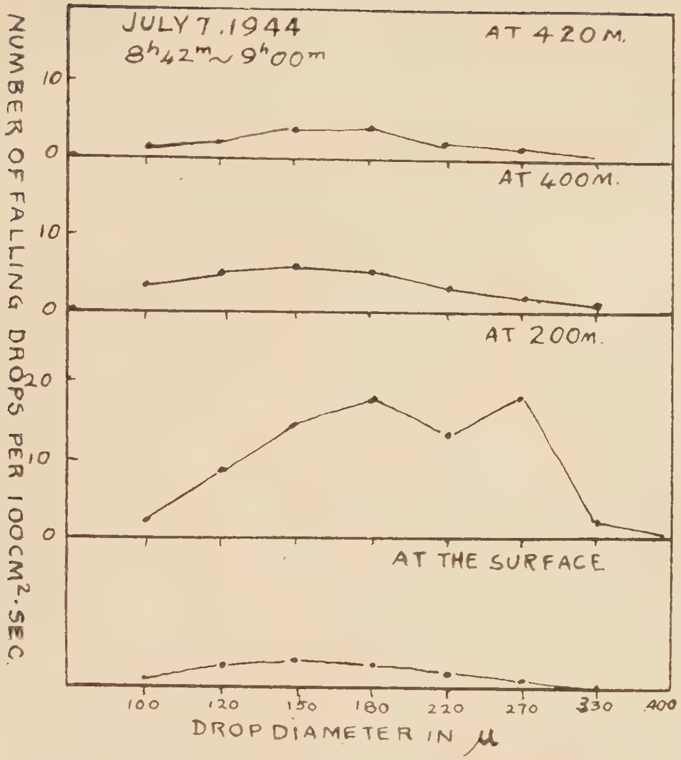


FIG. 7.—Example of the variation with height of drizzle accompanying sea fog or stratus. From the diagram it will be understood that the rain-producing layer lies at 200–400 m. above the ground and evaporation layer 0–200 m. Fog situation is as follows: 490 m., top; 490–430 m., density decreasing with height; 430–140 m., fog; 140 m., base; 140–40 m., hazy; 40–0 m., no fog.

(11) The observations at Nemuro show that in many cases the wind gets maximum velocity at a height of from 150 to 500 metres (see Figs. 4–6). This would be owing to topographical effects, but, as the height of maximum velocity generally coincides with the height of the top of the inversion, there might be some other causes.

(12) The vapour tension of the air above a fog or stratus layer is not low, except in some cases (see Fig 3).

(13) In the case of sea fog it is rare that the foggy air on the sea surface or on the ground is completely saturated, except in the case of very dense fog or at night when air temperature falls enough. Moreover, in the fog or stratus layer portions of unsaturated air are present, especially near the top and the base of the layer, and sometimes in the middle part of the layer. Such unsaturation cannot be explained by the depression of vapour pressure due to salinity of fog particles.

A NEW THEORY ON THE FORMATION OF SEA FOG

An outline of the theory which the present author has suggested is given below.

Here we make the following assumptions :—

(1) Let H be the height of the friction layer in the atmosphere, and U the wind velocity at that height. H and U are constant.

(2) Let A be the Austausch coefficient of the air above the inversion layer. A is constant.

(3) Let H′ be the height of the inversion. H′ increases through the upward transfer of cooling effect from below, as the air moves over cold water. Denote the wind velocity at H′ by u'.

(4) Let A′ be the Austausch coefficient of the air in the inversion layer. A′ is constant. This means that the air proceeds over the area where the water temperature of sea surface decreases rapidly leeward so that the steepness of the inversion is kept constant, for A′ depends closely on lapse-rate.

(5) The motion of the air in the friction layer is caused by the eddy transfer of momentum from the steady current of the air above the friction layer.

(6) The air is in steady motion.

(7) Frictional force at the sea surface is $\sigma\rho u_0{}^2$, where ρ is density of the air, u_0 wind velocity at the surface, and σ constant. For the ground σ will be nearly 0·004, but for the sea surface we shall take it as 0·0005 on account of its smoothness.

Now we shall consider the variation of wind velocity with height, when warm air has moved some distance over cold water and the inversion is present.

According to the assumptions wind velocity increases linearly with height in each layer from surface to H′ and from H′ to H.

Therefore the boundary condition at the sea surface is

$$A' \frac{u' - u_0}{H'} = \sigma\rho u_0{}^2$$

and at H′

$$A \frac{U - u'}{H - H'} = A' \frac{u' - u_0}{H'}$$

From these equations we obtain

$$u_0 = \frac{-1 + \sqrt{1 + 4MU}}{2M}, \text{ where } M = \sigma\rho\left(\frac{H'}{A'} + \frac{H - H'}{A}\right)$$

and

$$u' = u_0 + \frac{H'}{A'}\sigma\rho u_0{}^2$$

Now we shall calculate vertical distributions of wind velocity at two points where, for example, H′ = 400 m. and H′ = 500 m. respectively.

We take here H = 1,500 m., U = 10 m./sec., A = 100 g./cm.sec., A′ = 10 g./cm.sec., and ρ = 0·0012 g./cm.³. Then it follows that for H′ = 400 m.

$$u_0 = 4{\cdot}31 \text{ m./sec.}, \quad u' = 8{\cdot}77 \text{ m./sec.},$$

and for H′ = 500 m.

$$u_0 = 4{\cdot}07 \text{ m./sec.}, \quad u' = 9{\cdot}04 \text{ m./sec.}$$

Therefore, we are now able to draw the vertical distribution of wind velocity at these points in a diagram.

The results are shown at right in Fig. 8. As seen in the diagram, some retardation of wind velocity takes place in the inversion layer, as the air moves from the first point (H′ = 400 m.) to the next point (H′ = 500 m.). This causes ascending motion of the air in order to establish continuity.

For example, take the distance between two points as 10 km., then the magnitude of ascending component of the air at each height becomes such as illustrated at left in Fig. 8.

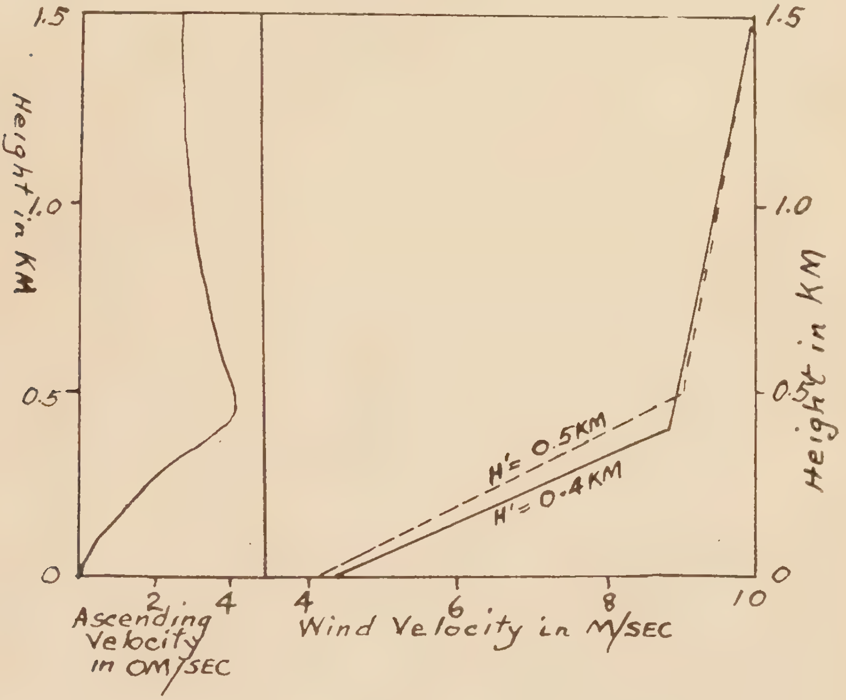


FIG. 8.

Thus it has been proved that ascending component exists in the air which moves over successively colder and colder water surface and consequently sea fogs are produced in the same way as ordinary cloud.

Indeed, sea fogs are much alike to the cloud which is formed in weak ascending current of the air, and accordingly sea fogs should be regarded as a type of cloud which forms at small distance above sea-level and often builds down to sea-level on account of very high humidity of the air over the sea.

ON THE MECHANISM OF HEAT THUNDERSTORMS AND SOME PROPERTIES OF CUMULO-NIMBUS IN JAPAN

By S. SAKURABA, Central Meteorological Observatory, Japan

THE heat thunderstorm which occurs most frequently in summer is investigated by aerological data, and some properties of cumulo-nimbus are discussed by the data from a dense network of observation points in the Kwanto District, Japan.

PART I—MECHANISM OF HEAT THUNDERSTORMS

To make clear the mechanism of heat thunderstorms or, in recent terminology, air mass thunderstorms, four-hourly radiosonde observations were made from 2nd to 17th August, 1944, at Maebasi, Gunma Prefecture, Kwanto District.

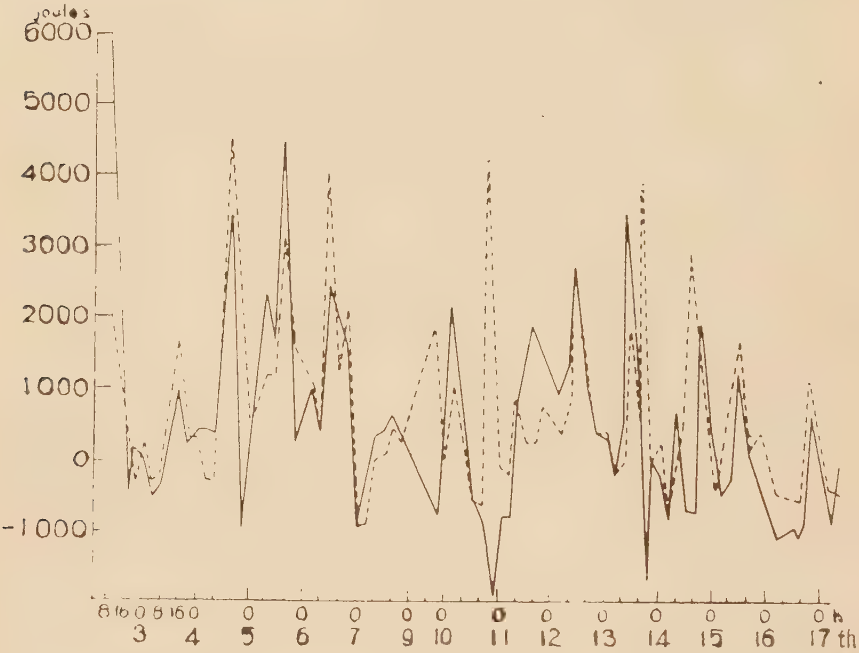


FIG. 1.

Figure 1 shows the variation of vertical lability determined from the sequent ascents every four hours, where the abscissa denotes the time of observation and the ordinate the labile energy in joules per 1 kg. air, vertical lability being expressed by vertical labile energy itself. Here the labile energy is computed by the parcel method widely applied in adiabatic charts, and becomes positive or negative according as the atmosphere is in conditional instability of real latent type or pseudolatent type (Petterssen, p. 62, 1940).

The thick lines in the figure denote the energies releasable when a lifting air parcel starts from the ground (which will be referred to as " surface " value later), while the dotted lines denote the mean values when the parcels start from several higher levels, including the ground level (which will be called " mean " value). They both show parallelism except a few cases.

Figure 2 denotes the mean diurnal variation of vertical lability, the maximum being at 14th–16th.

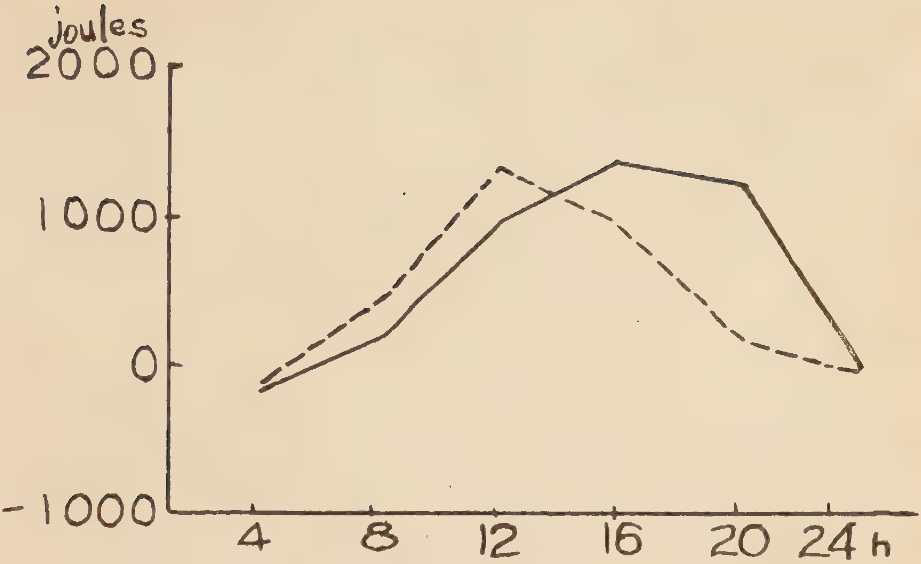


FIG. 2.

The analysis of the above result, taking into consideration pilot balloon, surface, and mountain observations, leads to the following conclusions, as to the mechanism of heat thunderstorms and alteration of vertical lability :—

(1) *Advective Change*—

(*a*) *Advection of Cold Air at the Level of Tropopause :* The labile energy is very large and exceeds 4,000 joules (mean value). Strong thunderstorm is produced.

(*b*) *Advection of Cold Air in the Lower Atmosphere :* The cold air comes from the Japan Sea side over the Jōetu Mountains, northern border of the Kwanto Plains, and rides over a heated unstable air stratum stagnant in the Plains in daytime. This unstable stratification causes the labile energy of 2,000–3,000 joules (surface value). Moderate or weak thunderstorm is produced.

(*c*) *Advection of Southerly Warm Air :* When the fresh southerly warm air invades from the Pacific Ocean side, the stratification becomes suddenly stable. This current is of different nature from local sea breeze.

(2) *Non-advective Change*—

(*a*) *Heating From the Ground :* The labile energy due to heating alone does not exceed 2,000 joules (surface value) and no thunderstorm is produced, only resulting in the development of moderate or weak cumulo-nimbus. Figure 2 should be interpreted as the mean diurnal variation of labile energy due to surface heating alone.

(*b*) *Stabilizing Action of Convection :* The labile energy is completely consumed within one to two hours by convective motion accompanying cumulo-nimbus. Therefore, in case of no energy supply, the duration of thunderstorm is one to two hours.

As is evident from the above analysis, the lability due to heating alone is not sufficient to cause thunderstorms, but the co-operation of heating and cold air advection is most important for the formation of heat thunderstorms, Roughly speaking, the labile energy due to surface heating is about 1,500 joules at most and that due to cold air advection is 1,500 joules or more. The co-operation of both agencies is most effective at the time of maximum heating energy ; therefore the present result does not contradict the statistical result of maximum occurrence of heat thunderstorms at about 14h.

It must be noted here that in the above discussion frontal or cyclonic thunderstorm is excluded.

Part II—Some Properties of Cumulo-nimbus

The following conclusions are drawn on the properties of thermic cumulo-nimbus from the data of dense network of temporary stations equipped with self-recording instruments (about thirty stations within the area of 100 km. square), which were specially distributed to investigate the minute structure of thunderstorms :—

(1) *Growth and Decay.*—The development of cumulo-nimbus is well explained by moist-labile energy alone from energetical point of view. The cold front accompanying the cloud has only secondary meaning for its development (see (3)). The amalgamation of cumulo-nimbus masses and the rejuvenation by amalgamation are also explained from the above point of view.

The moist-labile energy is rapidly consumed, so the cumulo-nimbus generally decays rapidly in energetically isolated environment. The air mass in old cumulo-nimbus is cold and stable, and of entirely different thermodynamical properties from the same cloud in developing stage, which shows the prevalence of radiational cooling.

(2) *Movement.*—The motion of developing cumulo-nimbus is governed by the law of amalgamation ; in other words, the cumulo-nimbus moves towards the region of more labile energy. The rejuvenation of cloud mass by amalgamation may be considered as the natural consequence of the above principle, while the old cumulo-nimbus is drifted by the upper current of 2–3 km. level.

(3) *Cold Front.*—The cold front is formed within the cloud mass, as the result of decending cold air (this front is local and must be distinguished from that in synoptic weather chart). The front generally moves faster than the cloud mass and runs outside the cloud, then it soon disappears. Sometimes front and cloud show different direction of motion. This is because they obey the different laws of motion. The above facts show that the cold front has no primary effect energetically upon the development of cumulo-nimbus. With the separation of front from cloud, the cloud decays, but, in developing cloud mass a new front is generated after the old front has gone away.

INVESTIGATION ON FOGS

By U. Nakaya, Hokkaido University

This report contains the results obtained by investigation on fogs occurring along the Pacific coasts of Hokkaido in the summers of 1944 and 1945. In the first year the investigation of the property of fog, the meteorological investigation on fog, and the preliminary investigation on the artificial dissipation of fog were mainly carried out by about thirty scientists at Nemuro, in the eastern end of Hokkaido. In these investigations balloon observation in fog and photographing of fog advection by means of slow-speed cine-camera were especially the effective means of investigation. In the second year, the experiment on " fog dissipation car," as a concrete method of the artificial dissipation of fog, was carried out at Tomakomai, in the southern coast of Hokkaido. Further, parallel with this experiment, preliminary tests on the method of measuring fog and on the artificial dissipation of fog were carried out at Kirigamine (1,925 m.), Nagano Prefecture and Nisekoan'nupuri (1,300 m.), Hokkaido.

The results of these investigations are summarized as follows :—

PART I—INVESTIGATIONS ON THE METHOD OF MEASUREMENTS OF FOG

1. H. Oguchi : *Method of Measurement of the Dimension and Number of Fog Particles*

Detailed investigations and discussions were carried out on the apparatus and its error measuring the dimension and number of fog particles by means of microscopic photographing of fog particles captured on oil membrane made on glass plate.

2. J. Sugaya : *Correction of Distribution Curve of Diameters of Fog Particles by Means of the Rate of Capture*

Noticing the difference of the rate of capture due to the dimension of fog particles in case of capturing them on glass plate, the method to correct the distribution curve of diameters of fog particles was discussed.

3. M. Hanashima : *Measurement of Total Amounts of Waters Contained in the Atmosphere*

A special apparatus was devised in order to capture, simply and with high accuracy even in open air, the total amounts of waters contained in the air of 20 litres passed through a small glass tube filled with mixture of glass cotton and phosphorous pentoxide.

4. K. Fukutomi, H. Kusunoke, and C. Tabata : *Measurement of the Amount of Fog Waters by Means of Meshes of Net*

An apparatus was devised in order to measure the amount of fog waters by capturing fog particles in the air with some gauzes or metal nets laid upon another. By means of this apparatus the dimension of the most frequent radius of fog particles can be known besides the amounts of fog waters.

5. K. Fukutomi and Y. Matsumura : *Rate of Capture of Fog Particles by Metal Net*

The experiments show how fog particles are captured in case of the passing of fog through metal nets. Particles are captured only when their centres hit the wires of metal nets.

6. K. Fukutomi and C. Tabata : *Trial Manufacture of Self-recorder of Amount of Fog Waters*

The continuous recording of the amounts of fog waters was made with pluviograph by leading fog particles captured by metal nets to it, and at the same time the wind velocity was self-recorded. By using both records the fluctuation of the amounts of fog waters in unit volume air was studied.

7. *N. Inoue, D. Kuroiwa, and Y. Takeuchi: Trial Manufacture of Electric Visibility Meter—(I) Summer Fog*

The trial manufacture of an apparatus was made, which is able to measure fog density through night and day by means of light source modulated adequately to photocell receiver. By using the apparatus the relation between fog density and visibility in summer fog and the fine fluctuation of density were studied.

8. *N. Inoue, H. Nakayama, and D. Kuroiwa: Trial Manufacture of Electric Visibility Meter—(II) Winter Fog*

By improving the electric visibility meter described previously in item 7 visibility in winter fog and snowfall and the relation between the discernible distance of light source and fog density were studied.

9. *N. Nakayama: On Method of Use of Wigand's Visibility Meter*

As the results of actual observation using Wigand's visibility meter it was clarified that error of 20–30 per cent. was caused by instrumental correction and personal error. However, a method was devised which reduces the error by means of measuring two slightly different distances and putting simultaneously three ground glasses with different density into the same visual field.

PART II—STUDIES OF PHYSICAL PROPERTIES OF FOG

10. *H. Oguchi: Measurement of the Radius of Fog Particles at Nemuro and at the Top of Mount Niseko*

According to the method of measurement mentioned in the item 1 above, diameters were measured for about 150,000 fog particles. These measurements were made in the surface level as well as in a balloon, to investigate the variation of diameter with height. The results thus obtained are as follows: (1) in the case of sea fogs at Nemuro the maximum frequency of diameter distribution was found in the range of 10 to 20μ, where the size of each particle was not uniform in general but mixed with more larger particles and fine rain-drops towards the lower level; (2) in the levels near the surface, fogs of dissipation type were frequent, with particles of smaller diameter; (3) cloud-particles at the top of the Mount Niseko were rather small and uniform in diameter; (4) it was found that the relation between visibility and diameter of fog-particle can be suitably represented by the Trabert's formula.

11. *J. Sugaya: On the Relation Between the Nature of Fog and the Diameter Distribution of Fog-particles*

As the results of observations the author identified two kinds of fogs—viz., dry and wet—the difference of which is to be attributed mainly to the rate of capture of fog-particles. In other words, the dryness of a fog becomes greater with increase of the wind speed and decrease of the size of fog-particle. On the basis of this opinion, the critical condition between dry and wet fog was studied.

12. *M. Hanashima: Measurement of the Total and Liquid Water Content of Fog*

By the method mentioned in the item 3 above the total water content in fog was measured, and, combining with the humidity values obtained from the concurrent observation by means of aspiration psychrometer, the liquid water content of fog was calculated. As the results of this it was found that the liquid water content of fog is 0·7 gram, on an average, and utmost about 1·0 gram in 1 cubic meter. These measurements were made on the ground as well as on a balloon.

13. *C. Magono: Measurement of Humidity in Fog by Means of the Aspiration Psychrometer*

As the results of humidity observation in fog by means of the aspiration psychrometer with a simple fog filter it was ascertained that in most cases the mean humidity in the fog is less than 100 per cent.

14. *N. Inoue and H. Nakayama: Fog and Snow-proof Wind Channel and and Electric Psychrometer*

Using the eddy current and the Cottrell's dust-collecting methods, the authors constructed a wind-channel, free from snow and fog, by means of which precise measurements of humidity were made. Also they devised a psychrometer utilizing the surface resistance of some organic substance against the leakage current to investigate the microscopic variation of humidity in the fog.

15. *H. Oguchi: Observations of the Condensation and Evaporation of Fog Particles*

On fine days just after rain the author observed how the water vapour evaporated from the surface of the earth, condenses into very fine fog particles by contact with the cold air mass advected from the ocean and how these fog particles evaporate again.

16. *N. Inoue and H. Nakayama: On the Visibility in Fog*

The errors in the observation of visibility arising from the difference in the size and colour of the visibility plate, personal error in estimating the visibility, and the difference of visibility in the horizontal and vertical direction were investigated. The authors also found that the visual range is at least 150 m. in the sea fog of Nemuro even in its densest case, while it can be frequently about 30 m. in the cloud at the top of the Mountain Niseko.

17. *J. Yoshida and K. Uno: Measurement of the Scattering of Light Due to Natural Fogs*

The authors measured the intensity of scattered light in the fog at the top of the Mountain Niseko by a simple lux-meter. As the results of this a maximum of the intensity of scattered light was found at the scattering angle of 142° for those fogs, consisting mainly of particles about 10μ in diameter, while there is not such a maximum in the case of haze, where the size of particles is fine.

18. *D. Kuroiwa and F. Tadano: A study on the Nucleus of Fog by Means of the Electronic Microscope*

Depositing fog particles on a collodion membrane, the authors investigated the remnants left after the evaporation of fog particles by means of an electronic microscope. After examining thirty cases, kinds of bacilli and the particles of aerosols were found, while the existence of the crystalline sea salt was quite rare.

19. *K. Fukutomi: Measurement of the Liquid Water Content of Fog and of the Amount of Chlorine Contained in the Large Drops of Fog by the Gauze Filtering Method*

The liquid water content of fog was measured by the method mentioned in the item 4 above, and a value of about 10 to 100 mg./m^3 was obtained. Also the amount of chlorine contained in the fog particles large enough to be captured by the gauze filter was measured. As the results of this it was found that this amount of chlorine is less for those fogs with more liquid content, being 7·4 mg./1 for fogs at Nemuro and 1·8 mg./1 for fogs at the top of the Mountain Niseko.

PART III—METEOROLOGICAL RESEARCHES ON FOG

20. *T. Isobe: Estimation of the Vertical Extent of Fog from the Amount of Insolation*

Comparing the records of insolation made by the Robitsch pyrheliometer and the vertical extents of fog measured by means of a balloon the author studied the relation between them, and ascertained that the vertical extent of fog in fair weather can be estimated by measuring the amount of insolation.

21. *Y. Miyake: Estimation of the Vertical Extent of Fog by Means of the Solar Ultra-violet Ray*

The author measured the absorption rate of the solar ultra-violet ray in the fog, and ascertained that the vertical extent of fog in fair weather can be approximately estimated by measuring ultra-violet radiation at the ground.

22. *U. Nakaya and H. Nakahara: Vertical Distribution of Illumination in Fog*

Authors investigated the vertical distribution of illumination in fog by means of a balloon equipped with a lux-meter, and found that the illumination increases almost linearly as we go higher up in the sky. By studying the relation between the rate of such increase of illumination and the nature of the fog it was ascertained that the vertical extent of fog can be estimated by measuring the illumination on the ground.

23. *U. Nakaya and K. Tsuneizumi: Relation Between Temperature Inversion and Fog*

Authors made observation of the vertical distribution of the air temperature in fog by means of a balloon almost every day in July and August, 1944. In most cases measurements could reach several hundred meters above the top of the fog, and details of the relations between fog and temperature inversion were revealed.

24. *J. Sugaya : Study of the Advection of Fog by Observations on a High Mountain*

The author made observations on the summit of Mountain Shari (1,650 meters in height), to the extent of 60 to 90 km. from the summit, of the speed and course of the advection of the sea fog, its relation to the wind direction, and the dissipation of fog, as well as the formation and dissipation of mountain fog.

25. *U. Nakaya and K. Yoshino : Study of the Advection of Fog by Means of Slow Speed Cinecameras*

Authors filmed the advection and dissipation of fog by slow-speed cameras installed (1) on Mount Shari, (2) on a balloon flown above the City of Nemuro, and (3) in the seashore of Katsuragi. By these means the aspects of the fog preceding a front, the dissipation of fog, the wave motion of a fog layer, the vortex motion in the uppermost layer of dissipating fog, and the dissipation near the ground were made clear.

26. *U. Nakaya, K. Takahashi, and H. Fuchi : Dissipation of Sea-fog as it Moves Landward*

In order to make clear how the sea fog is gradually dissipating being warmed at the ground as it moves landward, we made simultaneous observations at ten points within the range of three kilometers, of the variation of air and earth temperatures, humidity, fog particles, salinity, visibility, &c. According to these observations it may be concluded that the fog is practically dissipated when the air temperature rises about 3·5° c.

PART IV.—RESEARCHES ON ARTIFICIAL DISSIPATION

27. *K. Takahashi : Dissipation of Fog by Turbulence*

The author discussed the possibility of artificial dissipation of fog by causing the upper air of high potential temperature to fall to the ground in turbulence, utilizing the temperature inversion which accompanies the fog.

28. *K. Takahashi : Removal of Fog by Means of an Obstacle*

Since fog becomes thin on the lee side of a wood, the author made calculations to ascertain the size of this " shade of the fog " according to that of the wood and the speed of the wind.

29. *K. Takahashi : Dissipation of Fog by Heating*

The author experimented on the dissipation of fog by forming a hot spot on the ground, and, on the basis of the results obtained he calculated the minimum increase of the temperature needed for dissipating the fog, the process of the diffusion of heat, the loss of heat by radiation or turbulence, &c., and discussed the practicability of dissipating a large mass of fog.

30. *J. Yoshida : Measurement of Evaporation of Fog Particles*

Taking up the stationary state where fog particles from outside are disappearing, the velocity of evaporation of fog particles was observed

31. *T. Miyake: Miscellaneous Experiment Concerning the Artificial Dissipation of Fog*

The preliminary experiments on the method of artificial dissipation of fog such as by means of an absorbent, a wire-netting, heating and watering, &c., were performed to investigate to what extent these methods were effective.

32. *J. Yoshida, T. Takano, and D. Kuroiwa: Preliminary Investigation on the Thermal and Electrical Dissipation of Fog*

A fundamental experiment was performed to find out the amount of heat necessary for the dissipation of fog by electric heating and by hot air produced by combustion. Further, on the basis of the principle of Cottrell's dust-absorbing method, a method of catching fog particles was tested and the electric power needed for the dissipation was calculated.

33. *Y. Takahashi: Study on the Turbulence Relating to the Artificial Dissipation of Fog*

In case of artificial dissipation of fog in open spaces such as air fields, the dissipation efficiency decreases owing to the mixing of air current from another place by turbulence. To know the extent of the decrease in efficiency the vorticity in fog was measured by means of hot wire anemometer and resistence thermometer, and on the basis of this measurement the dimensions and distribution of dissipating sources were discussed. Further, as the result of the experimental measurement of eddy diffusivity in fog by streaming the cooled air into fog, it was found that an air current of — 5° c. was the most stable.

34. *J. Sugaya: Device of " Fog Dissipation Car " and its Calculation*

To dissipate fog at an airfield, the method of distribution of many movable heat sources was adopted and the equipment of a motor-car blowing out hot air produced by the combustion of heavy oil—that is, " Fog dissipation car "— was discussed.

35. *Y. Takahashi and J. Sugaya: Trial Manufacture of " Fog Dissipation Car "*

According to the condition described perviously in the item 34, a " fog dissipation car " was manufactured for trial whose main structure is composed of a combustion cylinder of heavy-oil, a blower blowing out the mixture of hot air and open air, and its motive power equipment. The trial car has the power as follows: consumption amount of heavy oil, 60 litres per hour. amount of air blowing, 3.7 m^3/sec. temperature of hot air, 70° c.

36. *U. Nakaya and J. Yoshida: Experiment on the Dissipation of Fog by Means of " Fog Dissipation Car "*

The experiment on the dissipation of fog was performed at the coast of Tomakomai by means of the " fog dissipation car " discussed previously. The range to be dissipated by the trial car amounted to 20 m. long, 5 m. wide, and 4 m. high. Further, it was shown that Takahashi's calculation of eddy diffusion described previously in the item 33 nearly held true.

ON THE SECONDARY UNDULATIONS OF TIDES CAUSED BY THE CYCLONIC STORM ON APRIL 1–5, 1936

By M. Nakano, Central Meteorological Observatory, Japan

[*Abstract*]

On the occasion of the cyclonic storm which swept along our Pacific coast from 1st to 5th of April, 1936, conspicuous secondary undulations appeared on the mareograms of tidal stations in various parts of this country. In the present paper is reported the result of investigation of periods, amplitudes as well as the time of occurrence of these conspicuous undulations, and some discussions are made on their relations with meteorological conditions. Figure 1 shows the positions of the tidal stations and the track of the centre of the cyclone, where the points marked with △, ×, ●, and ○ show the positions of the cyclonic centre at 0 h., 6 h., 12 h., and 18 h. respectively, and the numerals affixed beside the points give the corresponding atmospheric pressure (in mm. Hg) at the centre.

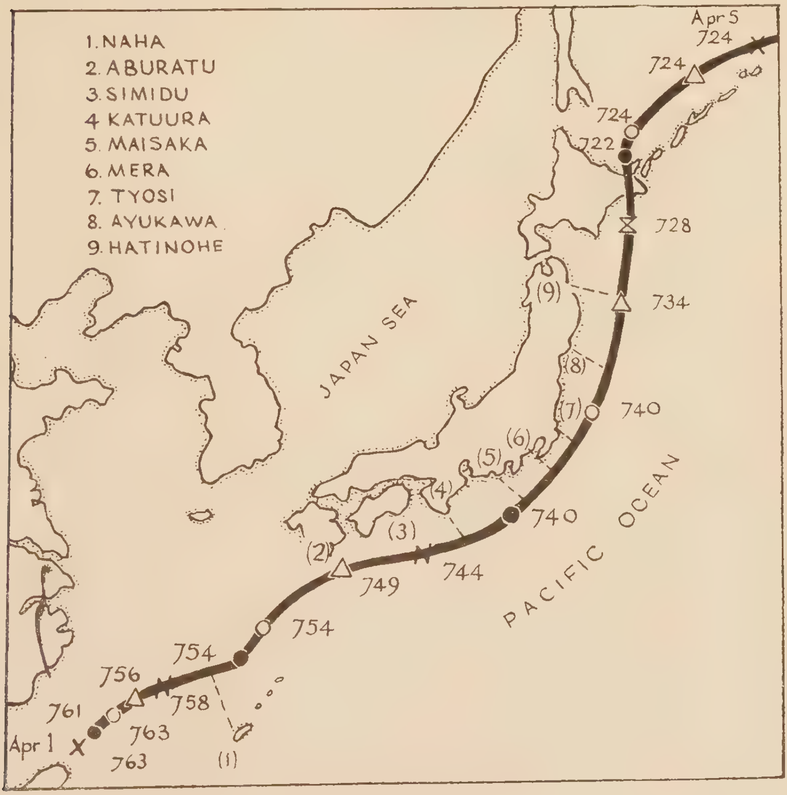

1. NAHA
2. ABURATU
3. SIMIDU
4 KATUURA
5. MAISAKA
6. MERA
7. TYOSI
8. AYUKAWA
9. HATINOHE
JAPAN SEA
PACIFIC OCEAN
Apr 5
724
724
724
722
728
734
740
740
744
749
754
754
756
758
761
763
763
Apr 1
(1)
(2)
(3)
(4)
(5)
(6)
(7)
(8)
(9)

Fig. 1.

On examining the mareograms at each station it was found that conspicuous undulations of longer periods, ranging from 5m–6m to 30m (proper oscillations of bays), generally began six to twelve hours before the arrival of the centre of the cyclone, whereas conspicuous undulations of shorter periods, ranging from 1m to 2m–3m, generally began somewhat later. This relation is illustrated by Fig. 2, where the time, T, is taken as abscissa, and the distance, △, of the respective stations along the path of the cyclone as ordinates, the origin of △ corresponding to the position of the cyclonic centre at 6 h. a.m., 1st April.

The thick full line represents the course of the centre of the cyclone or, in other words, the relation between the time T and the distance △ at the time when the centre of the cyclone attained the point nearest

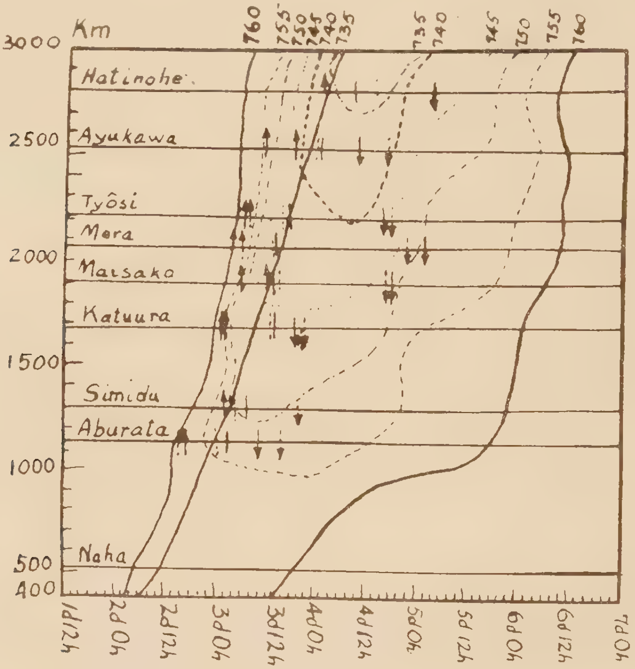


FIG. 2.

to the respective station. As seen from this curve, the travelling velocity of the cyclone was at first small, at the middle stage somewhat large, and later small again. From Aburatu to Hatinohe, however, this travelling velocity is nearly constant and approximates 67 km. per hour.

The time points marked with ↑ and ↓ correspond to the beginning and the end respectively of the conspicuous undulations of longer periods (proper oscillations of bays), and the points marked with ⇡ and ⇣ to the beginning and the end respectively of the conspicuous undulations of shorter periods (very long swells). Moreover the marks | and ¦ represent the time of maximum amplitude of the undulations of longer and shorter periods respectively.

Now in order to know the relation between these secondary undulations and the meteorological conditions, the course of different isobars during the course of the cyclone was traced by referring to the "Daily Weather Charts" and the "Monthly Reports" published from the Central Meteorological Observatory. The time of arrival and departure of the isobars of 760 mm., 755 mm., 750 mm., 745 mm., 740 mm., and 735 mm. for each station was estimated and was drawn in curves, which are shown in full lines, broken lines, chain-lines, &c., respectively in Fig. 2.

From this figure we can recognize that the beginning of the conspicuous undulations of longer periods, peculiar to each station, coincides nearly with the arrival of 755 mm. isobar.

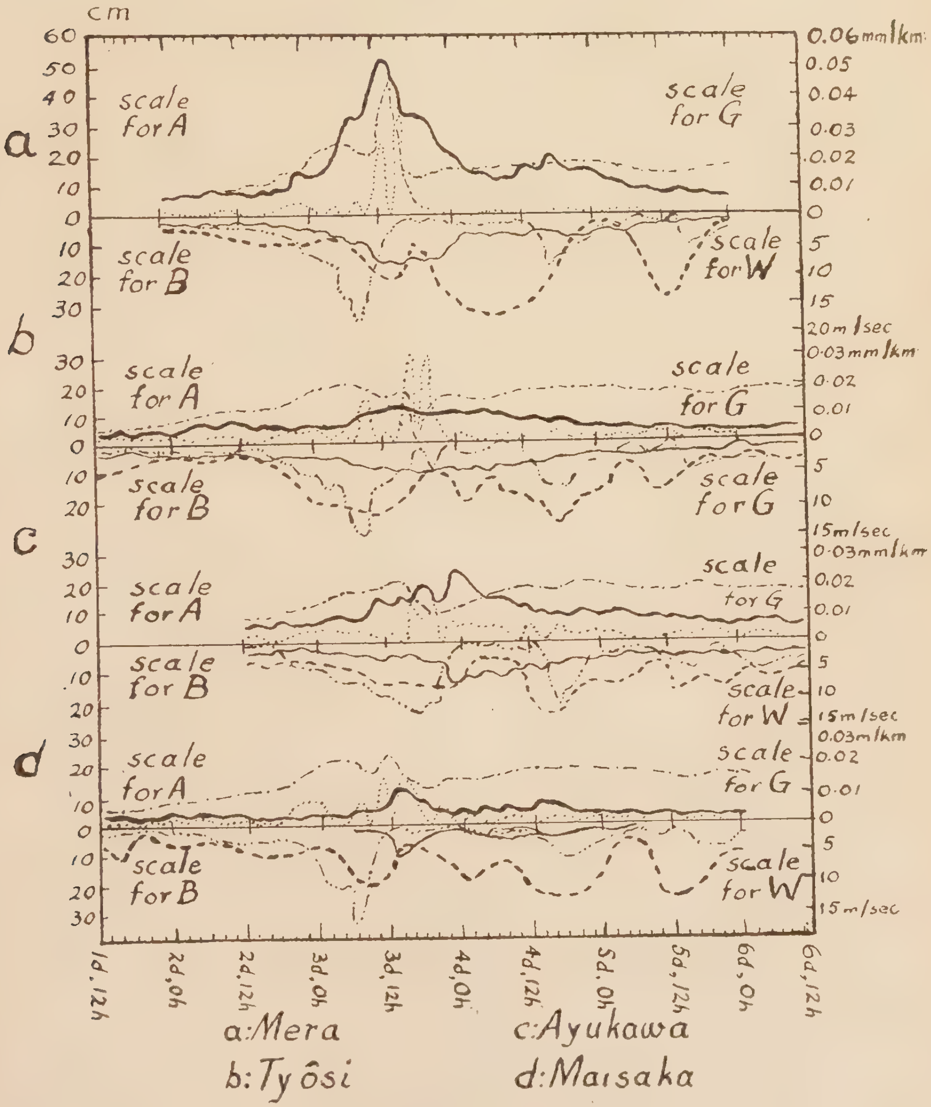


FIG. 3.

Figure 3 shows the relation between the range of the secondary undulations and various meteorological elements for some stations. The thick full line (▬) shows the range (double amplitude) A (in cm.) of the secondary undulations of longer periods (proper oscillations of bays), the thin full line (——) the range (double amplitude) B (in cm.) of the secondary undulations of shorter periods (very long swells), the thick broken lines (▬ ▬ ▬ ▬ ▬) the velocity of wind W (in m. sec.) at each station, the chain-line (—··—··—··) the magnitude of the rate of change of the atmospheric pressure P, the chain-line (—·—·—·—·) the pressure gradient G between the centre of the cyclone and each tidal station, and the dotted line (···········) the magnitude $\left|\frac{dG}{dt}\right|$ of the rate of change of the pressure gradient G.

In the following we shall summarize the results obtained from the present investigation :—

(1) For stations situated along the Pacific coast of Honsyu, Sikoku, and Kyusyu conspicuous undulations of longer periods (proper oscillations of bays) began six to twelve hours before the time of nearest approach of the cyclonic centre to respective stations, and conspicuous undulations of shorter periods (very long swells or waves of one to three minutes periods) generally began somewhat later.

(2) The conspicuous undulations of longer periods peculiar to the stations began about the time of arrival of the 755 mm. isobar at the respective station.

(3) The conspicuous secondary undulations under question seem to have no close relation with the velocity of wind, pressure gradient, or the rate of variation of atmospheric pressure in the vicinity of the tidal station.

(4) It seems that the present conspicuous undulations were not produced by the passage of lines of discontinuity and cold fronts or by local showers. Besides, it seems difficult to consider that the microbarographic oscillations in the vicinity of the tidal stations became the prime cause of the undulations.

(5) The secondary undulations in question seem to have some apparent relation with the time variation of the atmospheric pressure gradient—the amplitude of the undulations is large when the rate of change of the pressure gradient is large.

(6) It seems likely that the present conspicuous undulations were not produced directly by the meteorological changes in the immediate vicinity of the tidal stations, but chiefly by the waves which were produced in some region near the centre of the cyclone, perhaps by some microbarographic change, and propagated toward the tidal stations.

(7) As is naturally expected, the amplitude of the present secondary undulations has a close relation with the distance of the cyclonic centre from the tidal station. This relation is closer in the case of the undulations of shorter periods than those of longer periods.

(8) There is a tendency for the secondary undulation to be large when the depression of the cyclonic centre is low.

A detailed discussion will appear in a publication of the Central Meteorological Observatory in the near future.

A STATISTICAL STUDY OF CERTAIN UPPER AIR FACTORS RELATED TO TRADE-WIND RAINFALL IN HAWAII

By W. A. Mordy and L. B. Leopold, Pineapple Research Institute of Hawaii

[*Abstract*]

A statistical study is made of daily Honolulu radio-sonde data and daily rainfall parameters for days classified as trade-wind days. Variations in the factors of wind velocity, temperature, pressure, humidity, and stability are tested against variations in the daily average of ten high-rainfall stations and ten low-rainfall stations on Oahu.

The method is to compute the variance between the rainfall frequency distributions for each of two or three categories of values of temperature, wind velocity, and so on, testing for significance by using the Fisher variance ratio.

The factors expected to correlate best with the amounts of orographic rainfall on trade-wind days, such as wind speed and direction, moisture and stability in the layers below the subsidence inversion, do not show as high value of F as the factors of temperature and pressure at very high levels. Both temperature and pressure on these days show increasing correlation in the higher layers with rainfall.

SYMPOSIUM ON CLIMATOLOGY OF THE PACIFIC REGION

THE VARIABILITY OF RAINFALL OVER THE CENTRAL PACIFIC

By C. J. Seelye, Victoria University College, Wellington, New Zealand

[*Abstract*(¹)]

Rainfall information is conveyed by a series of maps covering the region between 10° N. and 30° S. and 150° E. and 150° W. These show the average annual rainfall and its percentage variability, the month of greatest and of least average rainfall, the frequency of wet months (taken as those with rainfalls exceeding 150 per cent. of average) and of dry months (under 50 per cent.), the last being given on a seasonal as well as on an annual basis.

Brief mention is made of surface winds in abnormally dry and wet years, of the persistence of dry months, and of several spells of exceptional rainfalls. Throughout the discussion the equatorial dry zone (with its south-eastern extension) figures prominently, as it has a rainfall regime distinct from the rest of the region. Its fluctuations, especially in the east-west direction, appear to produce substantial changes in the rainfall experienced in surrounding areas, and the importance of the westward flow of unmodified Tm air near the Equator is thus endorsed from the rainfall statistics examined.

DISCUSSION

In answer to a question by Dr. Priestley, Dr. Seelye said that unfortunately no data were available to investigate whether ocean currents might possibly have been the cause of some of the abnormal periods mentioned.

(¹) The full paper is to appear in the *New Zealand Journal of Science and Technology*.

In answer to a question by Mr. Mordy, Dr. Seelye stated that, with few exceptions, all the data could be fitted into the pattern shown by the charts.

In answer to a question by Mr. Simpson, Dr. Seelye stated that there were no reliable charts for this period on which to base correlations with the intensity of the zonal circulation, nor was there any information available to make a correlation with the intensity of the equatorial trough.

Dr. Gringorten remarked that the fluctuations in the northern and southern wet zones appeared to be simultaneous as judged by aircraft in-flight reports. Mr. Green was able to confirm this from his experience at Nandi.

Colonel Moorman stated that the back records from the former Japanese mandated islands have been collected and will shortly be published.

In answer to a question by Captain Best, Dr. Seelye stated that the distribution of rainfall at any one station was not normal, some curves exhibiting a high degree of skewness.

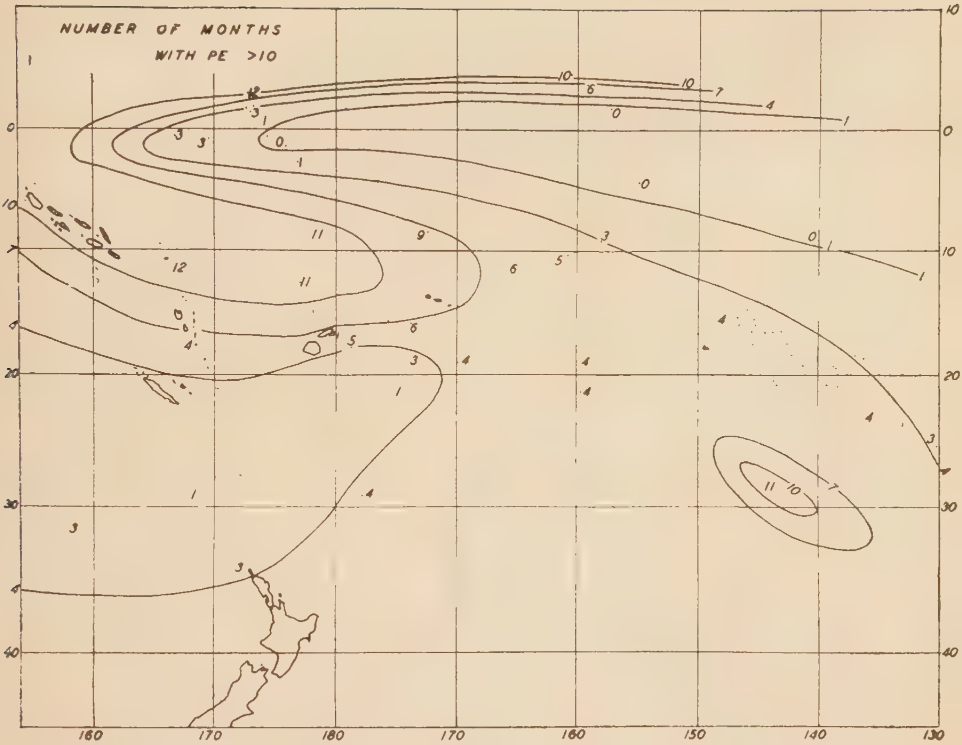
CLIMATOLOGY OF THE CENTRAL PACIFIC

By J. Gentilli, University of Western Australia

In the Proceedings of the Fifth Pacific Science Congress, held in Canada in 1933, Professor Gerhard Schott published a short paper on the distribution of rain over the Pacific Ocean (Schott, 1933). It was a brief paper because the author had already published a comprehensive study of annual and seasonal rainfall over this ocean elsewhere. The same author two years later published his major work on the Pacific and Indian Oceans (Schott, 1935).

In 1938 the Weather Bureau of the U.S. Department of Agriculture published an *Atlas of Climatic Charts of the Oceans* (U.S.W.B., 1938) which, for the Pacific Ocean, was based on 1,183,235 observations by ships scattered over 729 five-degree squares. These observations provide the most valuable and reliable source of material for the study of climate over the oceans, but, while they include average cloudiness and frequency of rain, they cannot give actual rainfall measurements. It is true that from a combination of the published maps showing the frequency of passing showers, steady rain, rain in whatever form, nimbus, cumulo-nimbus, stratus and strato-cumulus, cumulus, alto-cumulus and alto-stratus, cirrus with cirro-stratus and cirro-cumulus, it may be possible to estimate the actual amount of rain, but the result would only be a guess. One still has to use island observations in order to analyse the actual quantity of rain. Various meteorological offices have kindly made available some excellent material on which the following notes are based.

The significance of the rainfall is affected by the temperature at the time of fall and immediately afterwards, because any amount of rain that falls is subject to evaporation, which is a function of temperature and other factors, but principally temperature. A relatively simple way of estimating precipitation effectiveness has been evolved by Thornthwaite (1931), and it is this precipitation effectiveness that has been taken as a basis for research in this case.



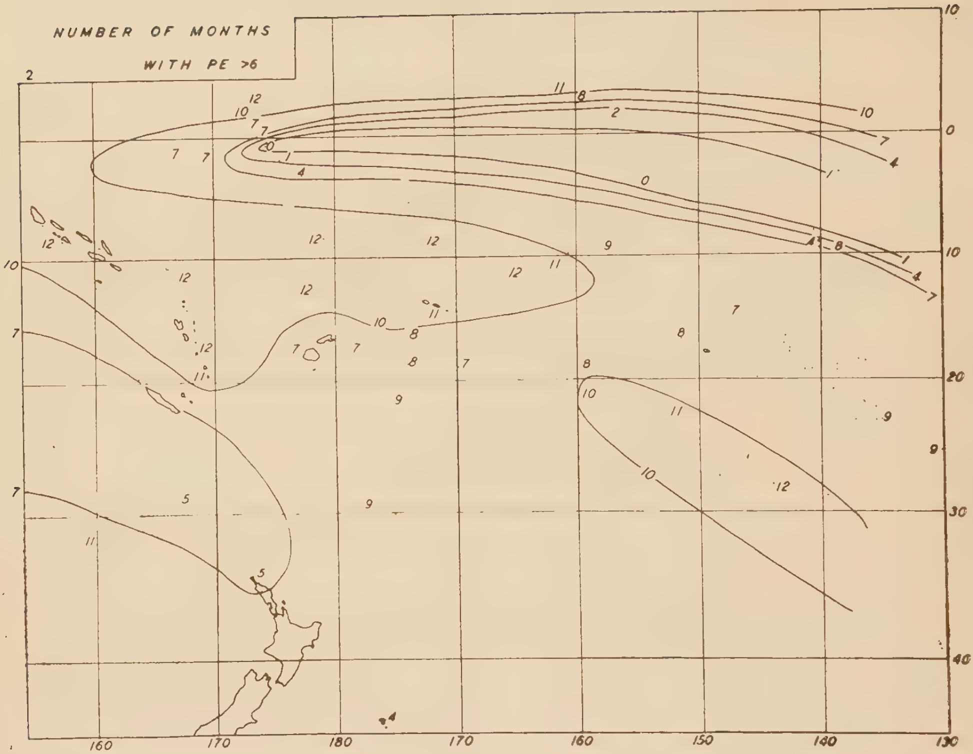
MAP 1.

Because of the tentative nature of this work it has been deemed desirable to limit it to the central Pacific, an area where islands abound and less interpolation is required.

Rainfall records are available for many islands, and temperature records for several of them. Whenever necessary, temperature records have been interpolated after having taken latitude and currents into account.

Precipitation effectiveness had hitherto been used in the assessment of climatic regions on the continents where it has usefully been correlated with vegetation regions (Thornthwaite, 1933). In this case, however, it was necessary to depart from the usual practice and to use precipitation effectiveness over the ocean as a basis for further research. It was also decided to rely on frequencies and on seasonal totals rather than on annual totals as was customarily done.

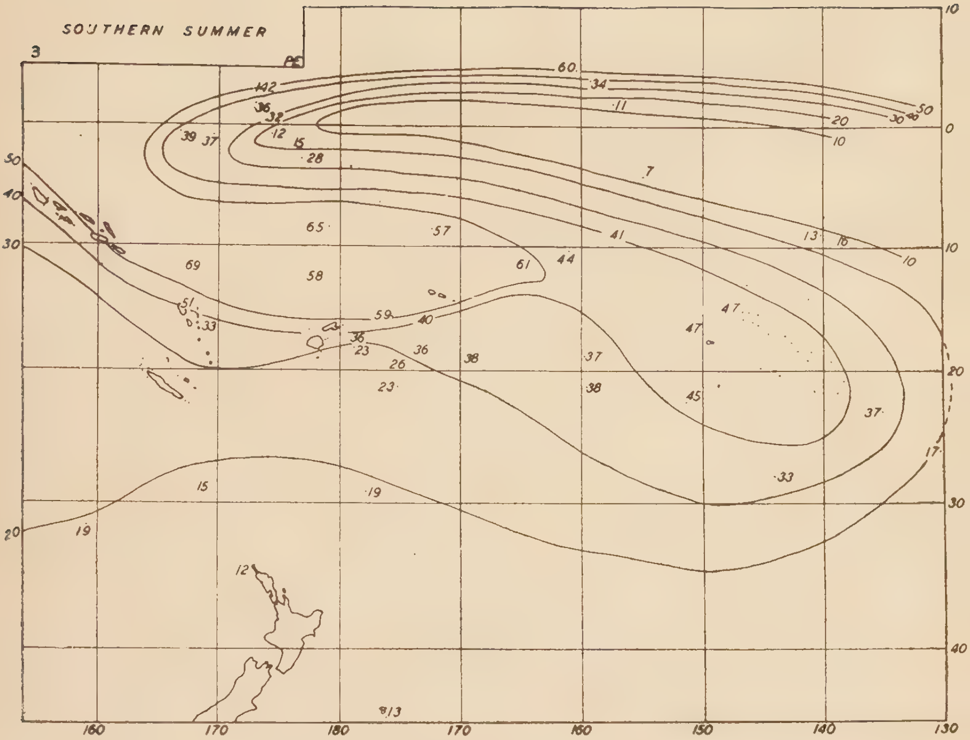
The main pattern which emerges from the following analysis is more complex than was earlier anticipated (Schott, 1933). There are the well-known dry tongue, which reaches along the Equator as far west as the Gilbert Islands, and the moist tongue, which reaches from the Solomon Islands to Samoa and farther east. However, the eastward extension of the moist tongue is subject to notable seasonal variations. A new region of high moisture is added in the region of Rapa. The Fijis are definitely drier than the New Hebrides, although the distance between the two groups is small and their latitude is approximately the same.



MAP 2.

After allowance had been made for orographical effects on the high islands it was found that the frequency of months with a precipitation effectiveness greater than 10 followed a distinctive pattern, as shown on Map 1. There are no months with this precipitation effectiveness along the dry tongue reaching from Beru (Gilbert Islands) to Christmas Island, widening towards the east to include Malden Island. This tongue is narrower than that postulated by Schott (1933) on the basis of rainfall alone. The belt of ocean with one to three months of precipitation effectiveness over 10 is concentric to the dry tongue, including Nauru, Tongareva (Penrhyn), and Pitcairn. This is approximately the area with less than seven months of precipitation effectiveness over 6, as shown on Map 2. Nauru and Ocean Island, however, have three months over 10 and seven months over 6, compared with Tongareva's and Pitcairn's three and nine respectively.

There is little seasonal variation within the dry tongue. Malden reaches a precipitation effectiveness of 15·4 for the southern autumn (Map 4), falling to 6·1 in winter (Map 6), to 2·4 in spring (Map 5), and rising again to 6·8 in summer (Map 3). The other islands in the vicinity show similar variations, and it may therefore be assumed that the dry tongue does not change its latitude throughout the year, but rather shows a greater or smaller advance westwards.


SOUTHERN SUMMER
3
60
42
34
36
32
11
12
15
28
39
37
20
10
50
30
7
65
57
41
13
16
10
69
58
61
44
51
33
59
40
47
47
36
23
26
36
38
37
38
45
37
23
17
33
15
19
19
12
13
160
170
180
170
160
150
140
130
10
0
10
20
30
40
50
40
30
20

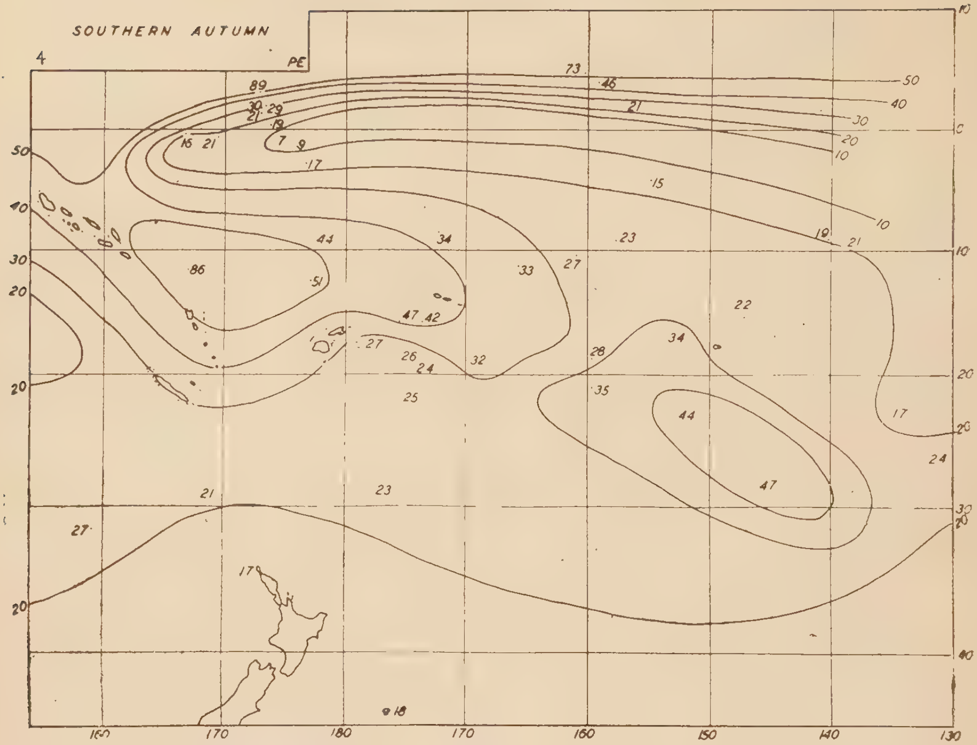
Map 3.

In view of the fact that the prevailing winds are almost invariably easterlies with a weak southerly component (U.S.W.B., 1938) it may be necessary to seek an explanation of the advance and retreat of the dry tongue in the conditions of the water surface at different times of the year.

In winter the southern Pacific is under the control of two great anticyclones, one centred about 100° W. and 25° S., the other one about 180° E. and 25° S. (Map 7B). The eastern anticyclone is generally recognized (Haurwitz and Austin, 1944), the western one links up with the Australian winter anticyclone and loses its identity. It is the eastern anticyclone that gives rise to the steady easterlies of winter between latitudes 2° and 12° S. These easterlies blow over a water surface which is as cool as 16° and 17° C. near the South American shore, and warms up progressively until it reaches 28° C. at about 177° E. along the Equator (Sverdrup and others, 1942). The air mass finds itself constantly warmer than the underlying surface, and its relative humidity decreases, notwithstanding the continuous intake of more moisture from the ocean surface.

In summer the same air mass travels over a water surface which varies in temperature between 21° and 28° C. over the same distance. The rise in temperature is only 7° C., as against 12° C. in winter.

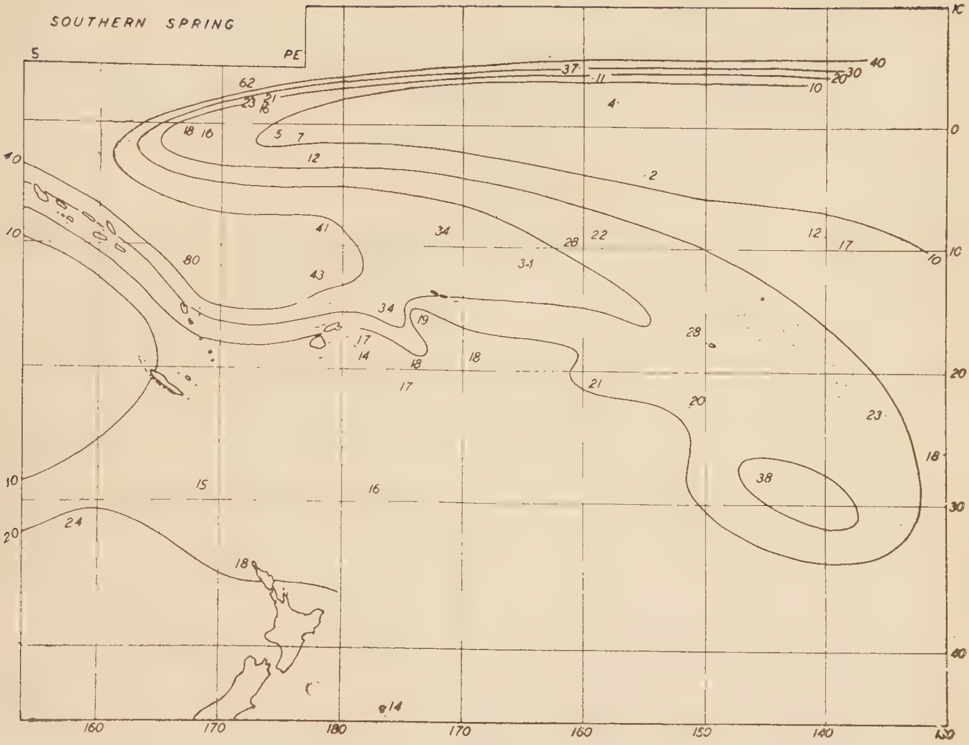
The moist tongue reaches from the Solomons to Samoa, but its eastward extension varies with the seasons. It always reaches as far as Pukapuka in the Danger Group, where summer is the wettest season,


SOUTHERN AUTUMN
4
PE
73
46
89
30
29
21
19
16
21
7
9
17
50
40
30
20
10
15
10
19
21
44
34
23
86
51
33
27
47
42
27
26
24
32
28
34
22
35
25
44
47
17
24
21
23
27
17
18
50
40
30
20
20
20
160
170
180
170
160
150
140
130
10
0
10
20
20
30
20
40

MAP 4.

followed by spring and autumn. Winter (Map 6) has the lowest precipitation effectiveness, less than one-half of that of summer. This seasonal pattern is quite different from the one shown by the Line Islands, of which Malden was quoted as an example. It resembles the seasonal pattern of the Gilbert Islands, much farther west. It may be advisable to seek a common factor underlying these similar patterns.

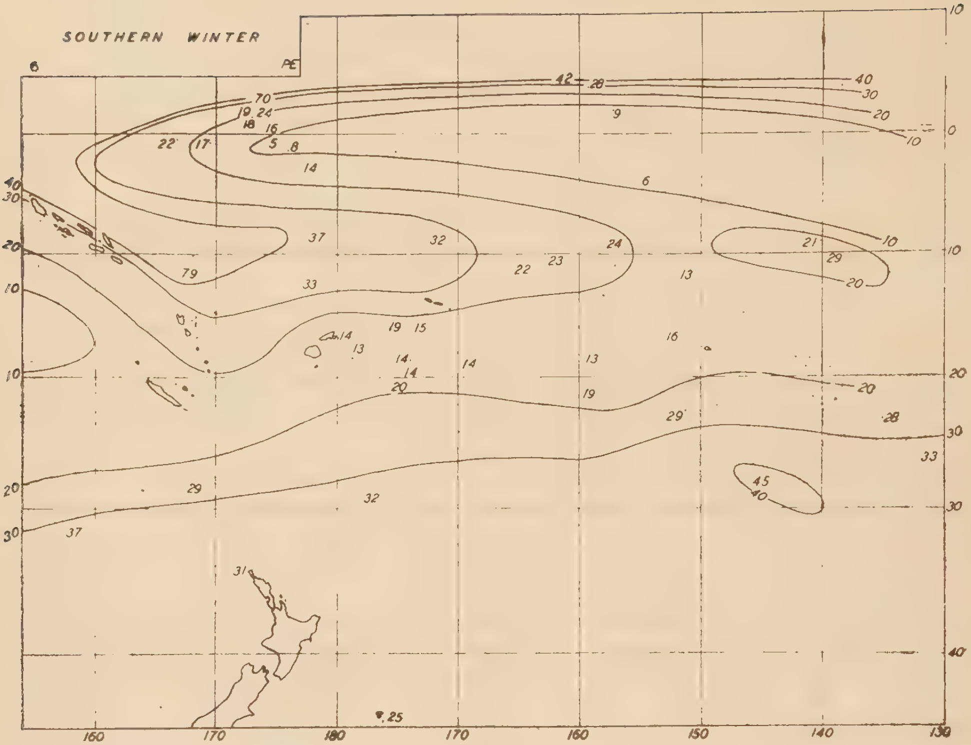
This factor is provided by the wind pattern (U.S.W.B., 1938). In the southern summer (Map 7A) the outflowing Asiatic monsoon causes a deflection of the north-east trades, which are greatly strengthened and are able to advance beyond the Equator as far as 175° W. and 15° S. in February. The intertropical front runs farther north than was postulated by Bergeron and other authors (Miller, 1946 ; Haurwitz and Austin, 1944), approximately along the boundary between Papua and the Territory of New Guinea, south of the Solomons, north of the New Hebrides to a point between the New Hebrides and Fiji, then north of Fiji to Samoa and Pukapuka. It is important to note that the western anticyclone of the South Pacific is well developed in summer, and its north-westward winds blow steadily as far as Fiji, which is thus kept relatively dry. These winds do not quite cover the New Hebrides, and thus allow the air masses from the Northern Hemisphere to sweep over these islands at times. In other words, the intertropical front is well stabilized north of Fiji, and moves slightly north and south over the New Hebrides, although its average position in February is just to the north of these islands.


SOUTHERN SPRING
PE
160
170
180
170
160
150
140
130
10
0
10
20
30
40
62
37
40
30
20
10
11
4
23
21
18
16
5
7
12
2
41
43
34
34
28
22
12
17
10
80
19
17
14
18
18
17
21
28
20
23
18
38
15
16
24
18
14

MAP 5.

Conditions show little change in March. By April the intertropical front runs over northern New Guinea, along the Solomons, to the north of the New Hebrides and Fiji. Here again the north-east trades may advance well over the New Hebrides, while Fiji is well under the influence of the south-east trades. High precipitation effectiveness is therefore found in autumn over the New Hebrides, and even as far as New Caledonia, whereas precipitation effectiveness is much lower in Fiji (Map 4).

In winter there is a tongue of high precipitation effectiveness running along the northern side of the Solomons and extending to Santa Cruz (Map 6). The precipitation effectiveness decreases slightly farther east, but the tongue is still clearly recognizable as far east as Manihiki and Tongareva (Penrhyn). The standard works on the subject do not mention the existence of any front, and convection due to heating is out of the question at this time of the year. The explanation here put forward is the formation of *shearing fronts* due to the convergence of air masses not from opposite directions as usually happens in normal fronts, but from directions forming an angle of 15 or 20 degrees only. These *shearing fronts* could only result in plentiful precipitation if the winds forming them were steady and strong and if the warmer air mass were quite unstable. They are provisionally shown with the stationary-front symbol on Maps 7A and 7B.

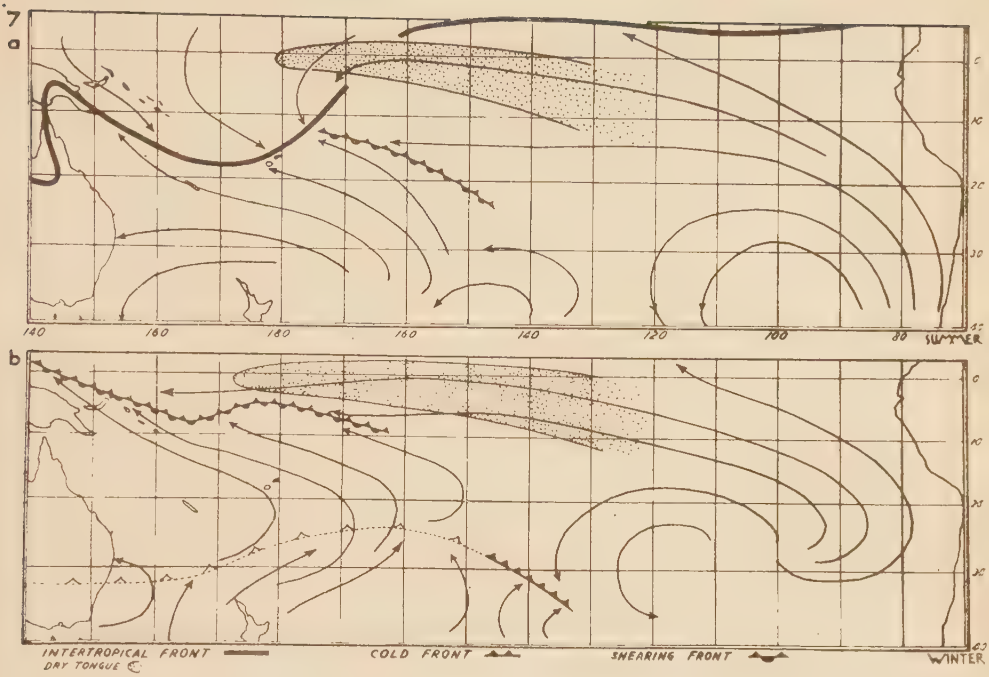

SOUTHERN WINTER
PE
70
42
28
40
30
20
10
9
22
17
19 24
18
16
5 8
14
6
37
32
24
21
29
20
79
33
22
23
13
19 15
14
13
16
14
14
20
19
29
20
28
33
29
32
45
40
37
31
25
160
170
180
170
160
150
140
130
10
0
10
20
30
40

Map 6.

The winter distribution of pressure systems over the southern Pacific has already been mentioned above. The eastern anticyclone sends strong winds which give rise to a shearing front between 135° and 145° W. when they meet the winds from the western anticyclone (Map 7B). The result is the relatively high precipitation effectiveness of the Marquesas in winter, much higher than that of the islands farther north or south (Map 6). Between 145° and 155° W. the winds from both anticyclones proceed in a parallel direction (U.S.W.B., 1938), and the precipitation effectiveness falls. Between 155° W., 12° S., and 150° E., 5° S. a much more effective shearing front develops between the westward flow from the eastern anticyclone, the west-north-westward flow from the westward one, and the strong north-westward flow from the Australian winter anticyclone under monsoonal influence (Map 7B). It is especially over the Santa Cruz and north of the Solomons that the shearing angle grows to nearly 45 degrees, thus giving rise to a much more effective front than was the case farther east.

The trades which arise from the western anticyclone continue to reduce the precipitation effectiveness of Fiji throughout the year.

The eastern shearing front which affects the Marquesas in winter disappears in the course of spring (Map 5) because the western anticyclone is greatly weakened (U.S.W.B., 1938). A new feature develops at this time farther south, between the Society Island and the Tubuai or Austral Islands, a small anticyclone centred at about 140° W. 35° S.



Map 7.

This gives rise to a seasonal front between 138° W., 35° S. and 155° W., 27° S., as is well shown by the map of precipitation effectiveness in spring. The highest precipitation effectiveness known for this zone in spring is found at Rapa (Map 5).

In the summer the small central anticyclone weakens and moves farther south (Map 3), so that no records are available except some signs of higher nebulosity (U.S.W.B., 1938). In autumn the area of high precipitation effectiveness reappears with greater intensity, extending farther to the north-west to include the Tubuai or Austral Islands as well as Rapa (Map 4). It is especially in late autumn (May) that precipitation effectiveness is high and it is at this time of the year that winds follow a complicated pattern (U.S.W.B., 1938) which has all the requirements for frontogenesis from Rapa to Tubuai.

In winter (Map 7B) the small central anticyclone tends to disappear between the two great anticyclones and Rapa finds itself just along the line of frontogenesis (135° W., 35° S. to 147° W., 28° S.) while the nearby islands have the usual incidence of fronts from travelling depressions as are found in these latitudes in winter. However high the winter precipitation effectiveness of Lord Howe Island, Norfolk Island, the Kermadecs, and Pitcairn may be it is not as high as that of Rapa, where actual frontogenesis takes place (Map 6). It is interesting to note that a front in the vicinity of Rapa had been postulated by Bergeron (Miller, 1946) and by Haurwitz and Austin (1944).

Summing up, the pattern which emerges from the present analysis is as follows :—

(*a*) A dry tongue along the Equator is due to water temperatures.
(*b*) A moist tongue immediately to the south is due to shearing fronts throughout the year, except in summer and early autumn, when it is due to the intertropical front.
(*c*) Shearing fronts are most noticeable in winter, and especially along the north-eastern edge of the Australian anticyclone.
(*d*) A definite frontogenetical area exists in the vicinity of Rapa.
(*e*) A small anticyclone tends to appear between the two great anticyclones of the southern Pacific at some times of the year.

REFERENCES

BYERS, H. R. (1944) : *General Meteorology*. New York.
Commonwealth of Australia (1940) : *Results of Rainfall Observations Made in Papua, &c.* Melbourne.
Etablissements Francais de l'Océanie (1940–1945) : *Resumé des observations faites en . . .* Papeete.
Fiji Meteorological Office (1948) : *Original records*. Suva.
HAURWITZ, B., and AUSTIN, J. M. (1944) : *Climatology*. New York.
MILLER, A. A. (1946) : *Climatology*. London.
New Zealand Meteorological Office (1943) : *Climatological Notes, South Pacific Region*. Wellington.
PETTERSSEN, S. (1940) : *Weather Analysis and Forecasting*. New York.
SCHOTT, G. (1933) : *The Distribution of Rain Over the Pacific Ocean* (in Proceedings of the Fifth Pacific Science Congress, III, 1933). Ottawa.
——— (1935) : *Geographie des Indischen und Stillen Ozeans*. Hamburg.
SHAW, N., and AUSTIN, ELAINE (1942) : *Manual of Meteorology*—Vol. II : *Comparative Meteorology*. Cambridge.
SVERDRUP, H. U. ; JOHNSON, M. W. ; and FLEMING, R. H. (1942) : *The Oceans*. New York.
THORNTHWAITE, C. W. (1931) : *The Climates of North America According to a New Classification*. (In Geog. R., XXI, 663.) New York.
U.S.W.B. (1938) = U.S. Department of Agriculture, Weather Bureau : *Atlas of Climatic Charts of the Oceans*. Washington.

DISCUSSION

The paper provoked considerable discussion, and many present were not entirely in agreement with some of the views put forward. In this connection Dr. Thomson expressed some doubt as to whether the formula for precipitation effectiveness could be applied in the Tropics. He pointed out that the formula was originally worked out only for a section of the eastern U.S.A. He considered, however, that further work should be done to test the applicability of the formula to other parts of the globe.

Mr. Simpson expressed his doubts that the low temperature of the sea-surface water was a cause of the dry zone observed near the Equator, but would rather consider the low temperatures of the surface water as a result of divergence in wind flow.

Mr. Rose pointed out that a Thornthwaite classification of climate had been attempted in New Zealand and that the formula for precipitation effectiveness seemed to have a broad general validity.

Dr. Spilhaus pointed out the great difficulty caused by orographical effects on rainfall of mountainous islands and doubted whether these gave any indication at all of the rainfall over the sea.

THE RAINFALL DISTRIBUTION IN THE PACIFIC REGION

By Takeshi Sekiguchi, Central Meteorological Observatory, Japan

[Abstract]

The islands of the Pacific do not show any remarkable relief so that we might expect the development of zonal climatic areas, especially with regard to rainfall. Up to the present the most precise information on the rainfall distribution was that published by G. Schott in 1933. Since then more precise and more numerous climatic data have come to hand from many stations in the Pacific. From these data a new rainfall map of the Pacific Ocean can be drawn (Fig. 2). This paper gives a description of the new rainfall map and attempts the classification of the Pacific into rainfall zones. It is pointed out that the rainfall of some of the Pacific islands shows very great variability, and a map of the annual variation of rainfall is presented (Fig. 1).

Discussion

It was agreed that the map was more reliable in the neighbourhood of the former Japanese mandated islands, but doubts were expressed as to the appropriateness of the values taken for the rainfall of such places as the Hawaiian Islands and the region north-east of the Cook Islands.

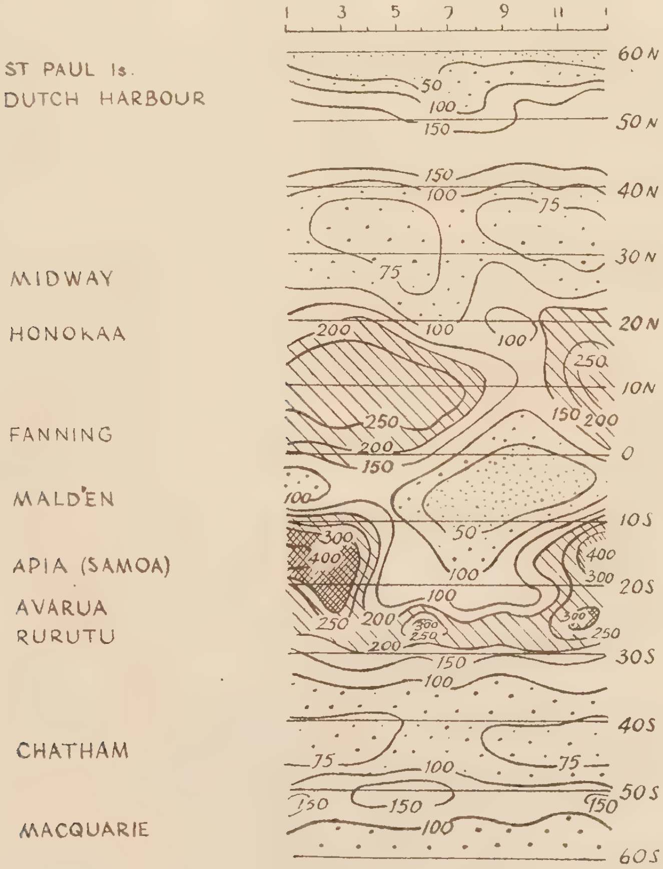


Fig. 1.

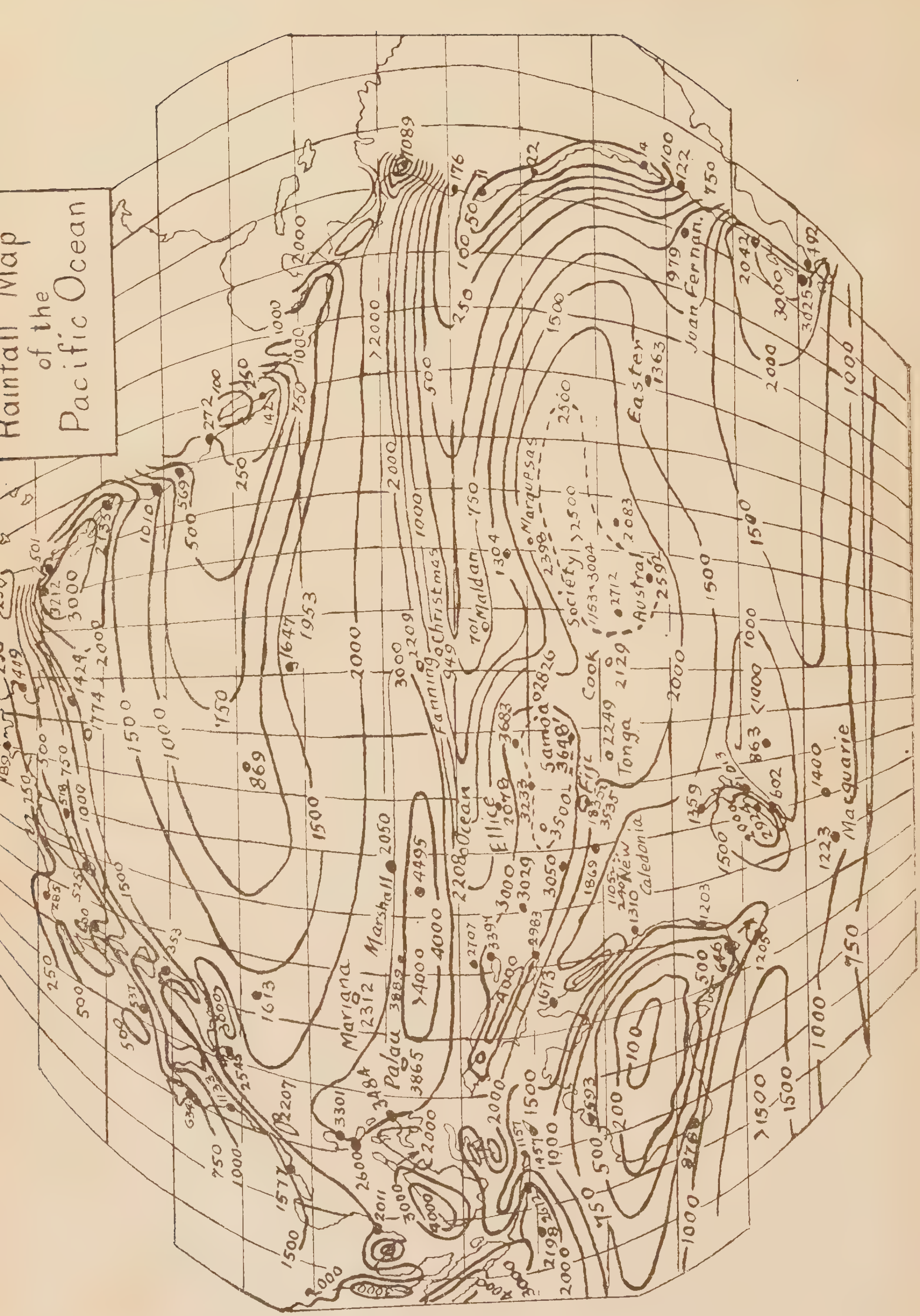

Rainfall Map of the Pacific Ocean
Mariana
Marshall
Palau
Ocean
Fanning
Christmas
Malden
Marquesas
Society
Austral
Cook
Tonga
Fiji
Samoa
Ellice
New Caledonia
Easter
Juan Fernan.
Macquarie

FIG. 2.

FLUCTUATIONS AND SECULAR TREND OF NEW ZEALAND RAINFALL

By C. J. Seelye, Victoria University College, New Zealand

[*Abstract*(¹)]

A list of annual rainfall indices for both North and South Island is given, the index being the average over a selection of stations of their rainfall expressed as a percentage of the 1911–40 mean. Accurate indices were obtained from 1911 to date, and with decreasing reliability back to 1852. In the majority of years the dispersion of rainfall amongst New Zealand stations has a standard deviation from 14 to 19 per cent.

The fluctuations from year to year are resolved into a longer period by smoothing, and the residual gives a shorter period. The coefficient of correlation of the former with sunspot number is 0·47 for the North Island and 0·31 for the South and over an average cycle the rainfall moves closely in phase with the sunspots through ranges of 13 and 4 per cent. in the two islands respectively. For the shorter fluctuation there is an average period of about three years and average range of 21 and 17 per cent. Both period and amplitude are irregular, and there is little similarity between the two islands except at or immediately after sunspot maximum.

Using moving thirty year means from the 1863–1947 indices average rates of decline of 4 per cent. and 2 per cent. per century for North and South Island are obtained. Recognition of a trend requires more critical examination of the indices before 1890 when isolated records cannot be satisfactorily reduced to standard epoch. Assuming the average trend of the island could be applied in such cases most of these earlier indices should be increased by 1 or 2 per cent. and the revised trends become 6·7 and 3·3 per cent. per century.

Further knowledge of the three-year cycle over the Pacific region seems desirable if the irregular variations noted are to contribute to any method of long range forecasting.

DISCUSSION

In the discussion Captain Best raised the question of the significance of the correlation coefficients given in this paper. Dr. Seelye replied that the graphical representation in his paper gave one more confidence in the correlation coefficients, and although they were not particularly high he thought that they were of significance.

Mr. B. W. Collins offered a very interesting contribution from the point of view of a ground-water geologist. The figures given by Mr. Collins showed that the level of ground-water in Canterbury in recent years tended to confirm the findings of Dr. Seelye. Dr. Berlage asked if a similar study with regard to seasonal variation of rainfall should not be undertaken. Dr. Seelye agreed that such a study would be well worth while.

In reply to a question by Mr. Mordy regarding the distribution of the stations used to compute the rainfall indices, Dr. Seelye replied that they were selected in the same way as those of the British Rainfall Organization, in order to give an adequate coverage of the rainfall of the whole country.

(¹) The full paper will appear in the *New Zealand Journal of Science and Technology.*

DROUGHTS IN NEW ZEALAND

By F. Bondy, New Zealand Meteorological Service

[*Abstract*(1)]

This paper discusses several aspects of the occurrence of absolute and partial droughts in New Zealand. The material is derived from the records of forty-six stations, these being selected to give as good a coverage of the Dominion as possible.

Absolute and partial droughts were classified according to their duration and expressed as percentages. Absolute droughts, in excess of six weeks, have been recorded at Nelson, North and Central Otago, and in several other places. In twenty-five of the forty-six stations the majority of the recorded partial droughts lasted into the sixth week.

Days lying within each absolute and partial drought were averaged by months and years for each of the stations. These averages when converted to percentages of the total number of days in the month or year provide a useful means of comparing the geographical and seasonal distribution. Naturally the areas with low rainfall will in general be those most subject to absolute and partial droughts, as is shown by a comparison of a map giving the distribution of droughts with an annual rainfall map. Differences evident in the North Island may be interpreted in terms of rainfall variability showing a close connection between high rainfall variability and high incidence of drought, and *vice versa*.

From the available figures it is possible to recognize at least three types of seasonal variation. In type " A," found in the northern, central, and south-western portions of the North Island and in Nelson, Marlborough, and the North Canterbury Districts, February is the month with the greatest number of days falling within a drought. At this time maximum anticyclonic conditions are normally present affecting the weather of the North Island and large portions of the South Island. Type " B," which is typical for the east of the southern half of the North Island, has its maximum in December and January. Heavy downpours connected with the passage of cyclones of tropical and subtropical origin in late summer and early autumn often break up the droughts. Type " C " gives a maximum in winter and is encountered in South Canterbury and Central Otago. This area is sheltered from rain-bringing westerlies, Central Otago also from south-easterlies, hence the dry winter. Threatened summer droughts are frequently broken by isolated showers of convectional origin.

The longest absolute drought recorded at any of the forty-six stations occurred at East Cape during the summer of 1927–1928 and lasted 64 days. The longest partial drought occurred in the winter of 1939 at Clyde. It lasted 176 days, during which 1·68 in. of rain fell. Droughts which have effected large portions of the country since the turn of the century occurred during the following seasons: summer, 1907–08; winter-spring, 1914; summer, 1916–17; summer-autumn, 1919; summer, 1927–28; summer, 1928–29; summer-autumn, 1930; summer, 1934–35; summer, 1938–39; summer, 1945–46; and summer, 1946–47.

A comparison of the average number of days belonging to partial droughts, computed for eighty years with a corresponding series of sunspot figures, shows a tendency of sunspot maxima to coincide within two years with drought minimum.

---

(1) The full paper, including tables and figures, has been submitted for publication in the *New Zealand Journal of Science and Technology*.

THE MEAN MONTHLY AIR TRANSPORT INTO THE CONTINENT OF AUSTRALIA, AND ITS SEASONAL VARIATION

By H. ARAKAWA, T. SAKITA, S. FUJII, I. FUJINUMA and T. HOSINO,
Central Meteorological Observatory, Japan

THE present paper treated the wind conditions around the continent of Australia on the basis of the pilot charts of the Indian Ocean, regularly issued by the Hydrographic Office of the U.S. Navy Department. The charts contain a great amount of information useful to sailors as well as weather men. This paper is a discussion of the wind conditions on the boundary part of the Continent of Australia, of which the representation of the wind is a point of chief interest. As to the interpretation of the wind roses, the following quotation from the text printed on the charts may give the best account.

> The wind roses in each 5-degree square show the frequency, the direction, and the average force of the winds that may be expected to prevail within that square. At the request of this office the wind percentages were concentrated upon eight points . . . The length of the arrow measured from the centre of the circles gives, by means of the attached scale, the number of times in each 100 observations that the wind may be expected to blow from the given point. The number of the feathers indicates the average force of the wind according to the Beaufort scale. The percentage of calms, light airs, and variable winds is shown by the number within the circle . . .

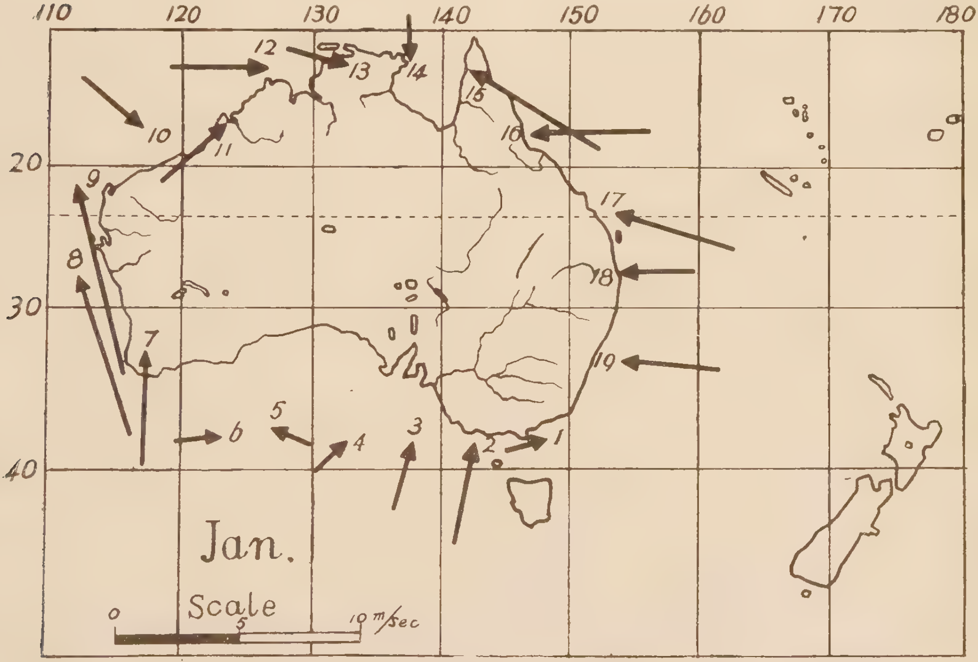


FIG. 1.

There are several different scales known as "Beaufort" in use. That adopted by the Hydrographic Office and Weather Bureau is known as the "Scott" scale and differs slightly from the English.

To get an immediate perception of the actual average air transport we calculated the resulting mean velocity, representing the average air

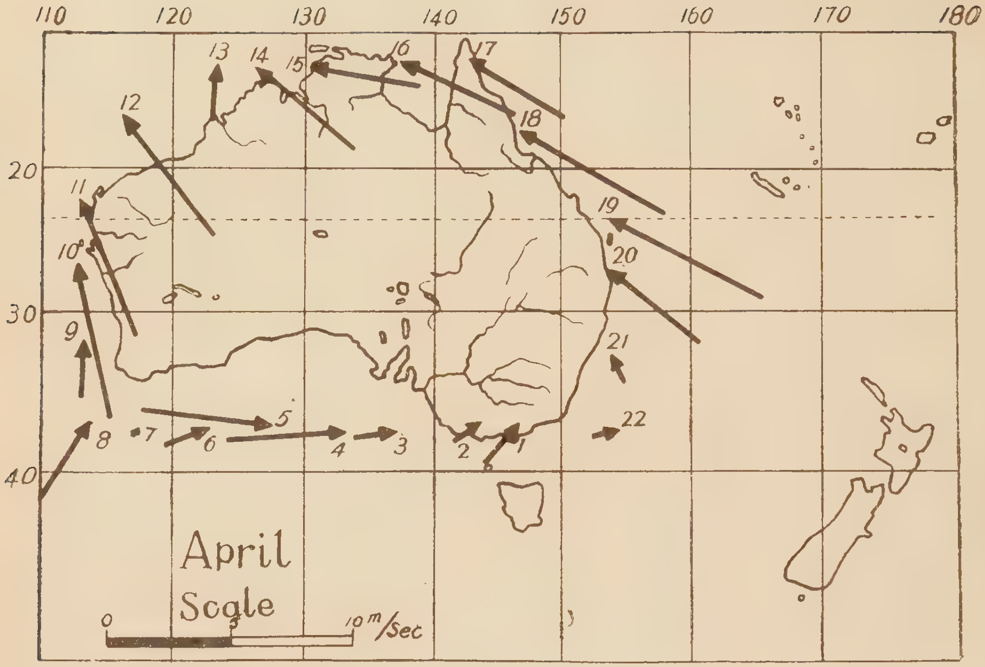


FIG. 2.

transport per second after W. Wereskiold's method(1). First the length of the arrows for each wind rose has been measured by the percentage scale. (Some few gross errors were, however, detected.) The next stage is to get the forces reduced to velocities. We have used simple averages of the limits of the velocities corresponding to each force, the tables being as follows :

Force (Beaufort).	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Velocity .. (m./sec.)	0·67	2·46	4·69	6·93	9·16	11·40	13·86	16·54	19·67	23·24	27·04

The graphic tables by W. Wereskiold, which give the mean velocity component in m./sec. in the N.–S. and the E.–W. directions were used quite frequently. The resulting components in the N.–S. and the E.–W. directions were found by simple addition and subtraction ; the result is written down by two components (N. and E.) for each wind rose. The magnitude of the mean resultant velocity (V) was calculated by the formula

$$V=\sqrt{N^2+E^2}$$

and the direction of the mean resultant velocity (α) was determined by the formula $\tan \alpha = \frac{E}{N}$, so the directions of N., E., S., and W. are given by 0°, 90°, 180°, and 270° respectively.

---

(1) *Geof. Publ.*, Vol. II, No. 9 (1922).

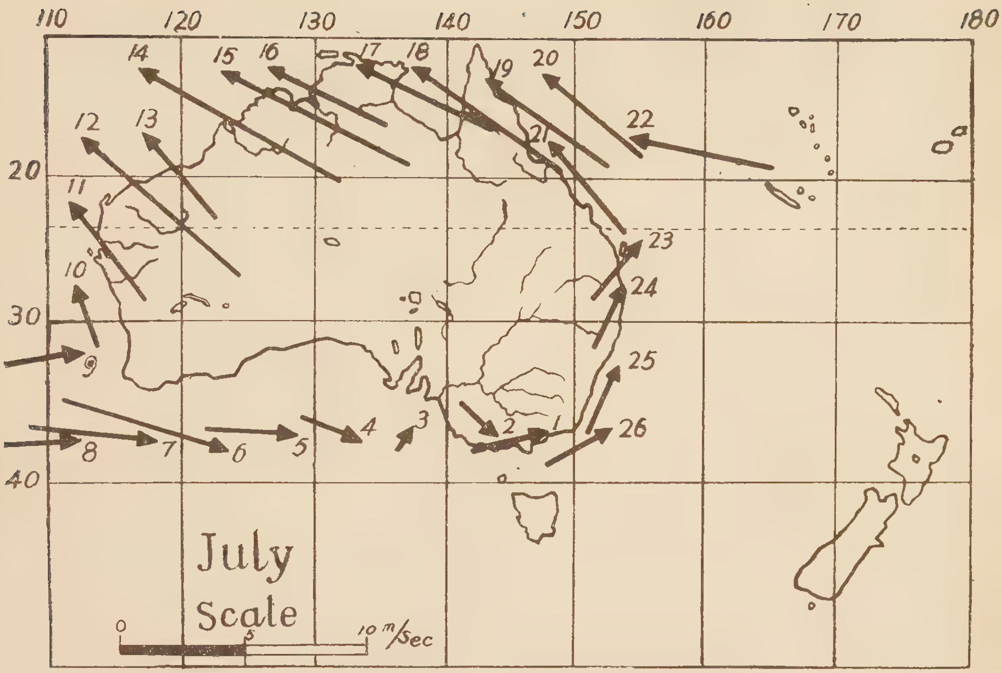

110
120
130
140
150
160
170
180
20
30
40
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
July
Scale
0
5
10 m/Sec

FIG. 3.

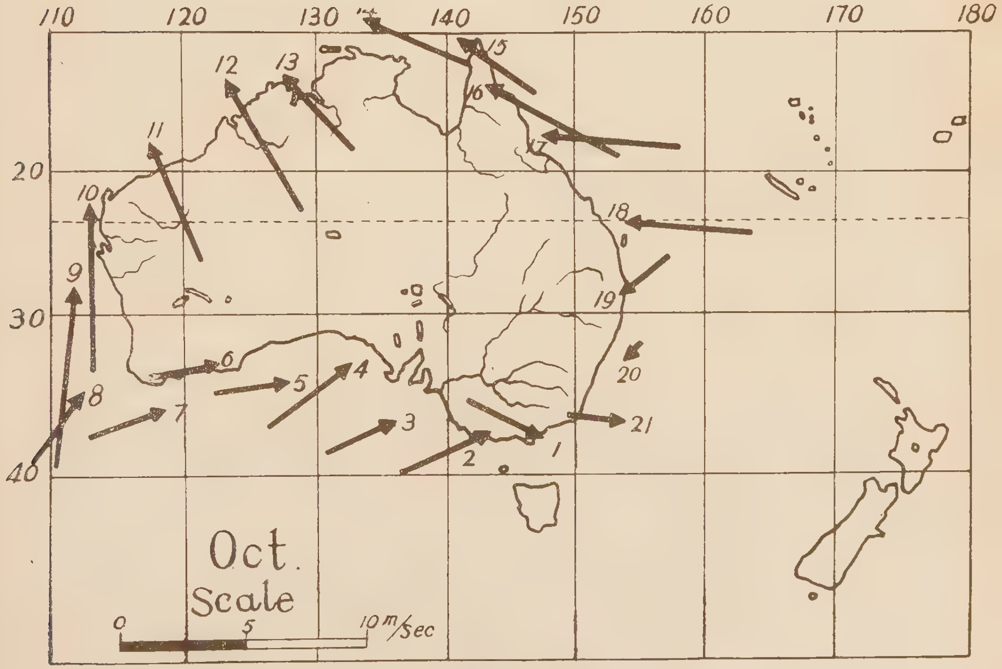

110
120
130
140
150
160
170
180
20
30
40
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
Oct.
Scale
0
5
10 m/Sec

FIG. 4.

The mean directions and velocities of wind were found and drawn in vectorial form in Figs. 1–4. One resultant wind vector, which has been drawn as an arrow, corresponds to each wind rose. The number attached to each vector indicates the region by the five-degree square, and the magnitude and direction of resulting velocities has been tabulated in table I according to this number.

TABLE I

No.	July.		October.		January.		April.	
	V (m./sec.).	α	V (m./sec.).	α	V (m./sec.).	α	V (m./sec.).	α
		° ′		° ′		° ′		° ′
1 ..	3·34	256 52	3·87	295 34	1·53	258 40	2·10	222 27
2 ..	1·99	315 39	4·21	244 32	4·27	190 50	1·39	236 50
3 ..	1·01	213 10	3·24	242 48	3·06	191 10	1·69	257 45
4 ..	2·54	291 15	4·42	233 11	1·70	229 50	5·13	264 24
5 ..	3·48	272 18	3·35	265 23	1·80	109 20	5·55	277 0
6 ..	6·95	286 36	3·28	259 49	1·83	262 0	1·93	251 16
7 ..	4·93	278 9	3·27	253 27	4·90	181 10	0·29	257 35
8 ..	3·49	267 16	4·09	214 56	6·83	162 10	3·71	211 40
9 ..	3·43	260 33	7·62	185 30	7·90	166 10	2·24	179 14
10 ..	2·35	159 40	6·75	180 0	3·49	309 10	6·24	169 53
11 ..	4·42	144 10	5·45	156 12	3·53	255 0	6·39	158 14
12 ..	8·91	132 16	6·39	142 42	4·34	269 10	6·12	140 6
13 ..	4·76	139 16	4·41	136 6	2·89	284 10	1·94	185 52
14 ..	9·18	118 15	4·51	111 20	1·90	360 0	5·15	127 50
15 ..	8·78	116 37	5·38	122 29	4·03	119 50	5·09	99 0
16 ..	5·46	115 36	6·44	115 17	5·20	90 0	5·15	112 20
17 ..	6·24	113 55	5·84	94 25	5·19	105 40	4·56	116 10
18 ..	7·49	123 17	5·41	93 17	3·20	88 40	6·69	119 7
19 ..	6·68	124 12	2·48	50 25	4·21	93 50	7·32	117 42
20 ..	5·45	127 56	0·75	46 5	..	..	4·70	128 23
21 ..	5·28	138 30	3·54	279 59	..	..	1·11	153 54
22 ..	6·15	101 20	..	..	..	..	1·17	246 56
23 ..	2·89	134 35	..	..	..	..	..	..
24 ..	2·76	221 6	..	..	..	..	..	..
25 ..	3·21	205 40	..	..	..	..	..	..
26 ..	3·49	240 50	..	..	..	..	..	..

Assuming that the air current is the same throughout the lowest 1 km. layer, the total amount of mean monthly air transport (per second) into the Continent of Australia was found to be as follows :—

——	January.	April.	July.	October.
Total flow into the Continent of Australia	21·05 x 10^9 m.^{3}/sec.	10·84 x 10^9 m.^{3}/sec.	8·78 x 10^9 m.^{3}/sec.	16·96 x 10^9 m.^{3}/sec.
Total flow out of the Continent of Australia	4·96 x 10^9	9·98 x 10^9	24·84 x 10^9	16·32 x 10^9
Net air-flow into the Continent of Australia	16·09 x 10^9	0·86 x 10^9	−16·06 x 10^9	0·64 x 10^9
Length of the coast of Australia used in computation	9,777 km.	12,127 km.	13,382 km.	12,351 km.

Under the assumptions described above, the net air-flow into the Continent of Australia in January, April, July, and October is estimated roughly, as 16 × 10^9 m.^{3}/sec., 0·86 × 10^9 m.^{3}/sec., −16 × 10^9 m.^{3}/sec., and 0·64 × 10^9 m.^{3}/sec. respectively. The net air-flow out of the Continent of Australia in July explains the predominant descending motion over this continent and the resulting fair weather. Further assuming that the absolute humidity of the air flowing into the continent is about 10 g./m.^{3}, the total amounts of water vapour flowing into this continent are—

For January	16×10^{10} g./sec.
For April	$0\cdot86 \times 10^{10}$ g./sec.
For July	————————
For October	$0\cdot64 \times 10^{10}$ g./sec.

respectively. If these amounts of water vapour are wholly condensed by the converging-ascending motion, the resulting average precipitations over the Continent of Australia are estimated as—

For January	56 mm.
For March	3 mm.
For July	..
For October	2 mm.

Naturally, the air-transport flowing into the continent must be compensated by the diverging air in the upper layer over the continent.

CLIMATIC CHANGE OBSERVED IN JAPAN

By TAKEO YAMAMOTO, Ube Technical College, Japan

1. INTRODUCTION

A. WAGNER(1) showed the fact that the climate has changed with a tendency for the annual variations of air temperatures to decrease in Europe in the past ever since instrumental observations were established. As for Japan, H. Arakawa(2, 3) pointed out that, barring seeming changes due to the expansion of cities like Tokyo, Osaka, and Kyoto, the mean annual temperature of any place has been practically constant during the past fifty years, thereby concluding that the secular change of the Japanese climate is too imperceptible to be affirmed. This is one fact to be noted, but as climatic change ought to be defined in due consideration of variation in the character of all factors bearing on the annual weather conditions, the annual ranges of air temperatures observed in Japan, for example, also requests careful study in this connection, and the problems concerning the climate change in Japan are to be reinvestigated.

2. SECULAR CHANGE OF ANNUAL RANGES OF AIR TEMPERATURE OBSERVED IN JAPAN

With ten-year means of the data I found that the air temperatures in winter season (December, January, and February) are lowering and in summer (June, July, and August) are rising up to the present indicating extreme parts around 1900 A.D. in almost all the regions in Japan as shown in Fig. 1, in which the curves of secular change of winter and summer temperatures are made by smoothing ten-year means by the formula $\frac{a + 2b + c.}{4}$

I have calculated the annual range of air temperature in each year taking first term of sine series expanded from yearly change of air temperature by the method of harmonic analysis. As will be seen in

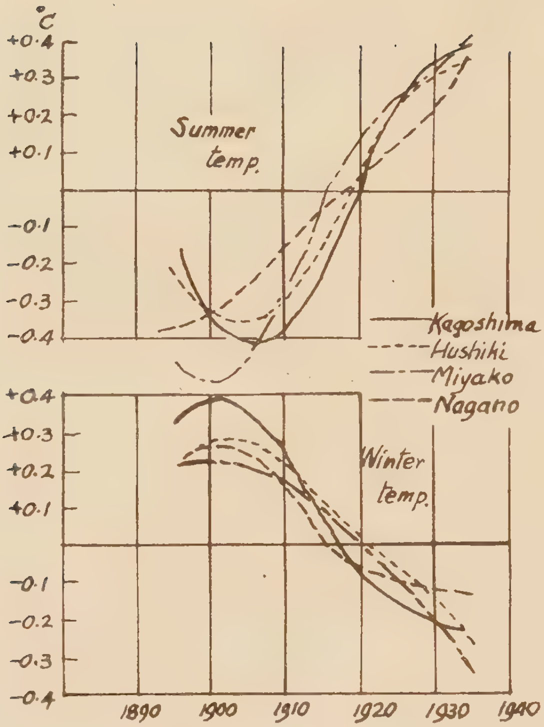


FIG. 1.—General aspect of secular variation of air temperatures in Japan.

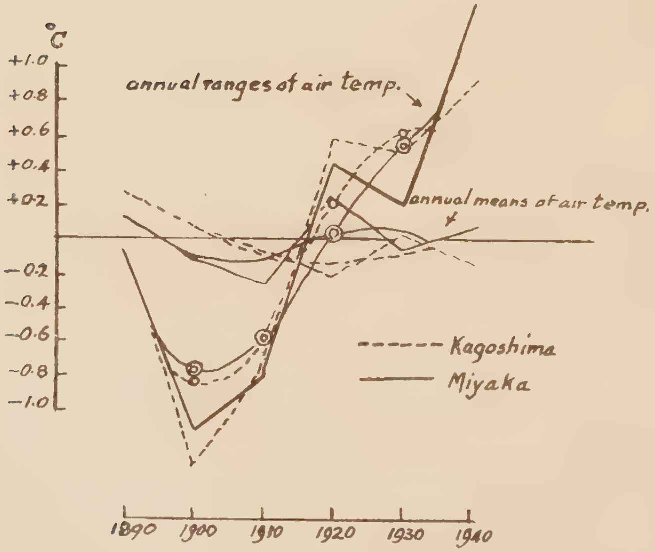


FIG. 2.—Secular changes of annual ranges of air temperature compared with those of annual means of air temperatures at Kagoshima.

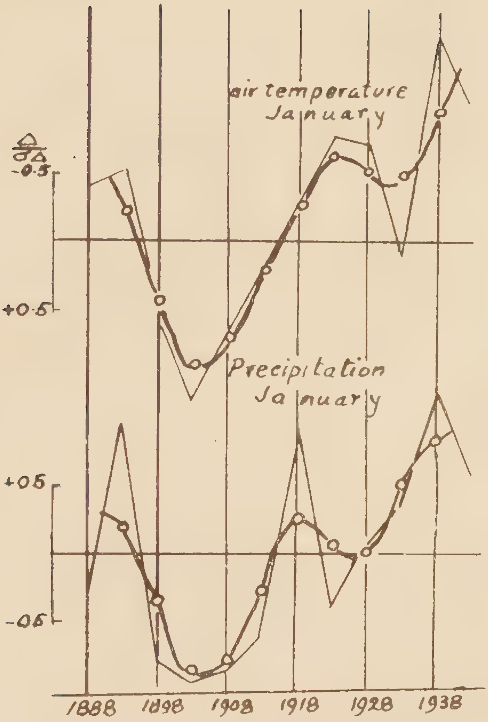


FIG. 3.—Secular changes of air temperature and precipitation in January at Hushiki.

the following Table I, there exists in the change of ten-year means of annual ranges of air temperature marked and widespread trends such as are never found in the annual mean of air temperatures (see Fig. 2).

In order to explain the character of the above-mentioned climatic trends of Japan more minutely I like to begin with the observation data gained at Hushiki, a meteorological observation station along the Japan Sea. Figure 3 shows the curves of secular variations of air temperature and precipitations in January at Hushiki, obtained by smoothing the successive five-year mean according to the formula $\frac{a + 2b + c}{4}$, while Fig. 4 shows the curves of the secular variation of air temperatures as well as precipitations in the summer season (from June to August) at Hushiki, obtained by the same method as in the case of midwinter. Comparing them one will find to one's surprise the quite similar form between the curves of winter and summer, the co-ordinate of midwinter temperatures and precipitations being taken positive respectively downwards and upwards, *vice versa* in the case of summer. The summer temperatures at Hushiki rise in the same process in which the midwinter temperatures fall, and as for the precipitations the same thing can be observed.

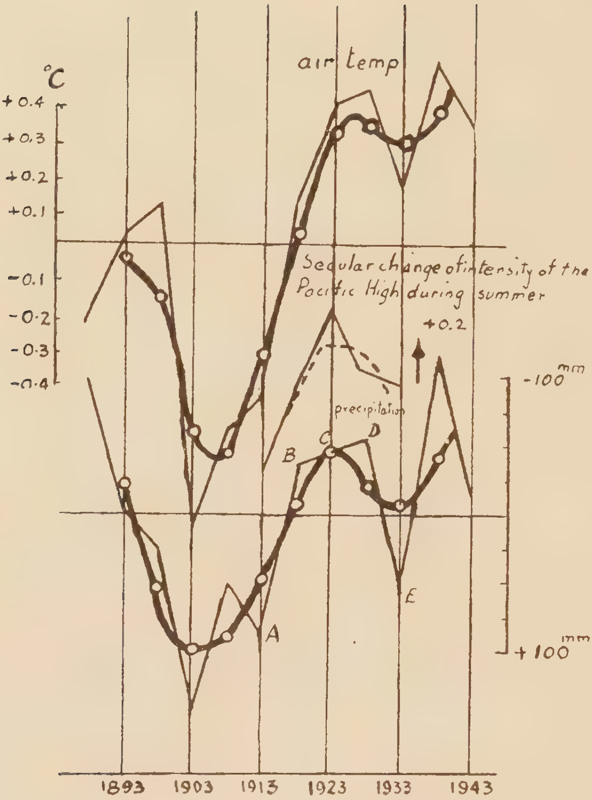


FIG. 4.—Secular variation of air temperature and precipitation during summer of Hushiki.

The striking contrast between the features of secular variation of summer and winter climate especially of air temperatures as above mentioned is to be found not only at Hushiki, but also in almost all the parts of Japan. I have calculated the correlation coefficient between ten year means of summer temperatures (June, July, and August) and that of winter (December, January, and February) at twenty places(1) scattered on Kyushu, Shikoku, and the Japan Proper, as shown in Fig. 5 the value of the coefficient being $r = -(0{\cdot}61 \pm 0{\cdot}06)$.

Generally speaking, the climate of Japan has changed, increasing the annual range of air temperatures—that is to say, growing gradually colder in winter and gradually warmer in summer during the past fifty years.

---

(1) Kagoshima, Hukuoka, Hiroshima, Sakai, Kochi, Wakayama, Hikone, Tu, Hamamatsu, Nagano, Choshi, Utsunomiya, Hukushima, Yamagata, Miyako, Hukui, Tsuruga, Hushiki, Niigata, Akita.

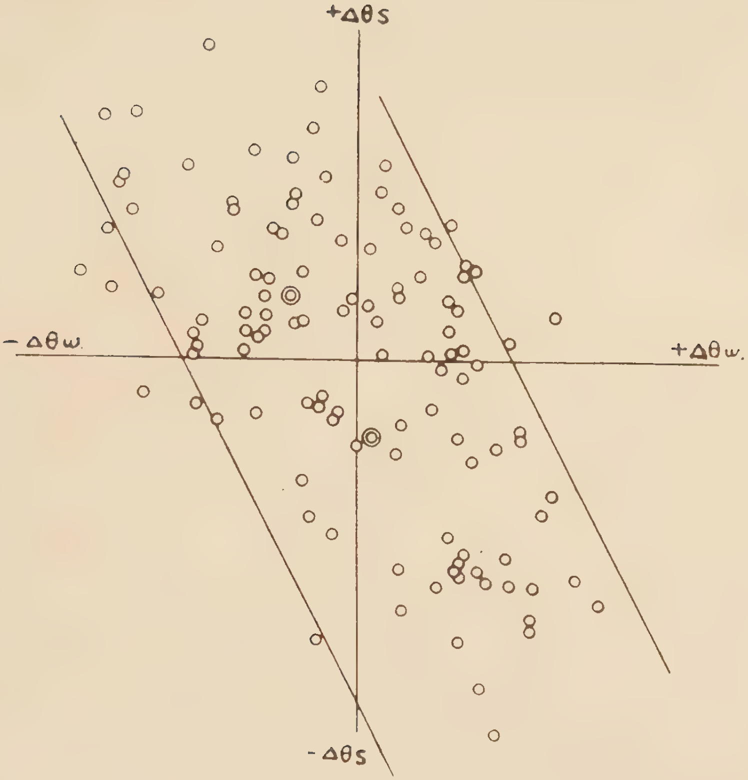


FIG. 5.—Correlation of ten year means of summer temperatures with those of winter temperatures at various places in Japan.

3. THE METEOROLOGICAL MECHANISM OF THE SECULAR TRENDS OF JAPANESE CLIMATE

It is a well-known fact that the climate of Japan in winter is chiefly influenced by the Siberian High, and that in summer it is influenced by the North Pacific High. As for the case of winter, the cold air current originating from the Siberian High prevails over Japan Islands, bringing much precipitation in the districts along the Japan Sea by passing over the sea warmer than the continent. The secular trends of air temperatures and precipitation in midwinter observed at Hushiki, as shown in Fig. 3, are ascribable to the rise and fall of the intensity of the geostrophic wind, which is proportional to $\frac{\delta p}{\delta n}$ —*i.e.*, the pressure difference of two points fixed on the normal line of mean isobar-curves. I have taken up the pressure difference between Nikolsk (long. 131° 57′ E. ; lat. 43° 47′) and Asahigawa (long. 143° 22′ E. ; lat. 43° 47′) in January, which correlates very clearly in each individual year with the data of air temperatures in January at various places in Japan as shown in Fig. 6.

On the other hand, the action centres governing the weather of the Far East in summer exists in the high pressure area over the North Pacific Ocean, the so called North Pacific High. The temperature in

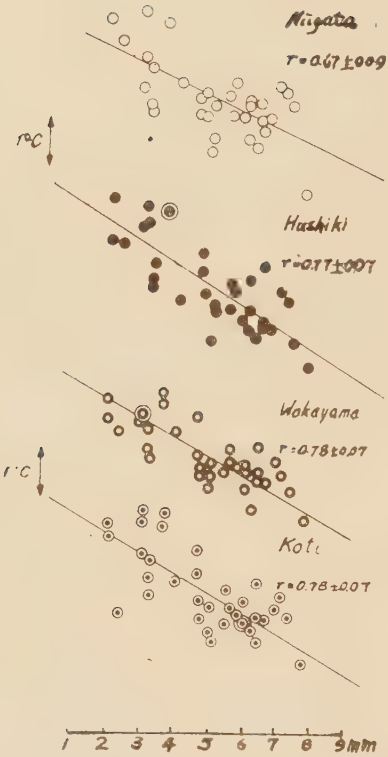


FIG. 6.—Correlation of air temperature in January with pressure differential between Nikolsk and Asahigawa.

summer rises due to the air current from the low latitude zone revolving with the North Pacific High on its right. Using the ledgers of weather charts published at Kobe Marine Observatory, I have investigated the change of the five-year means of pressures of the area within the rectangle, bounded by longitude 180° E. to 130° W. and latitude 25° N. to 50° N. for the period from 1911 to 1935. As shown in Fig. 7, the curve of the secular change of intensity of pressures within the rectangular area, which is obtained by averaging the data of each section divided by every longitude 5° and latitude 5°, is in good harmony with that of summer air temperatures as well as precipitations at Hushiki.

The curves of secular trend of the amount of precipitation observed in central part of the Japan Proper are shown in Fig. 7; with the increase of the intensity of the North Pacific High, the high-pressure zone extends over the Japan Proper and diminishes the amount of precipitation in the said district, by pushing the isobar-curves northwards, along which depressions tend to proceed(4).

The above-described various facts seem to lead us to the conclusion that the Siberian High in winter as well as the Pacific High in summer have been heightened, since around 1900 A.D., in other words, the

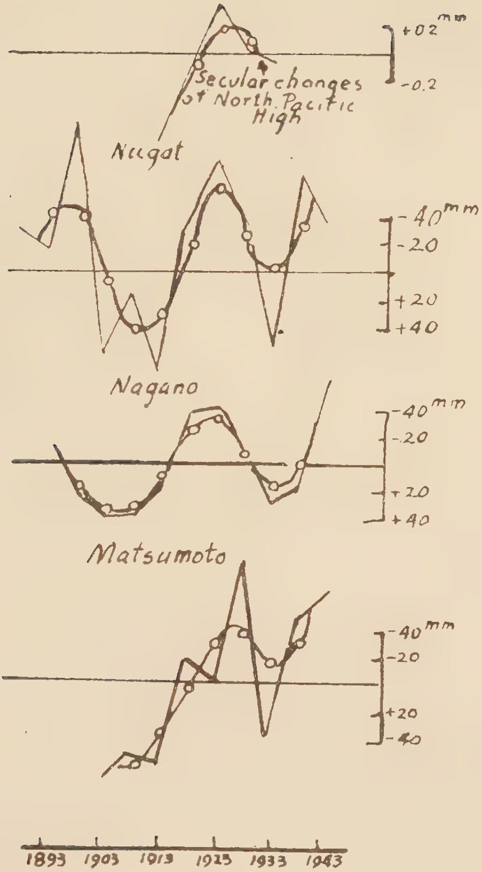


FIG. 7.—The secular change of the amount of precipitation during summer season in the central part of Japan proper

intensities of winter and summer monsoons in the Far East have been increasing in the past fifty years, and that is the cause which has widened the annual range of air temperatures in the most part of Japan as I showed in the preceding paragraph.

4. THE SUN'S ACTIVITY AS A POSSIBLE FACTOR ON THE SECULAR CHANGE OF CLIMATE

As above stated, it can fairly be concluded that the changes observable in the climate of Japan are due to the fact that the monsoons, both in winter and summer, in the Far East are growing active. A. Wagner(5) and others(6) have also referred to the increasing activity of the general circulations of atmosphere in their attempts to explain the trend of climatic change in Europe. Collating all the information available, it is conceivable that the general current of atmosphere over the northern hemisphere has gained in intensity.

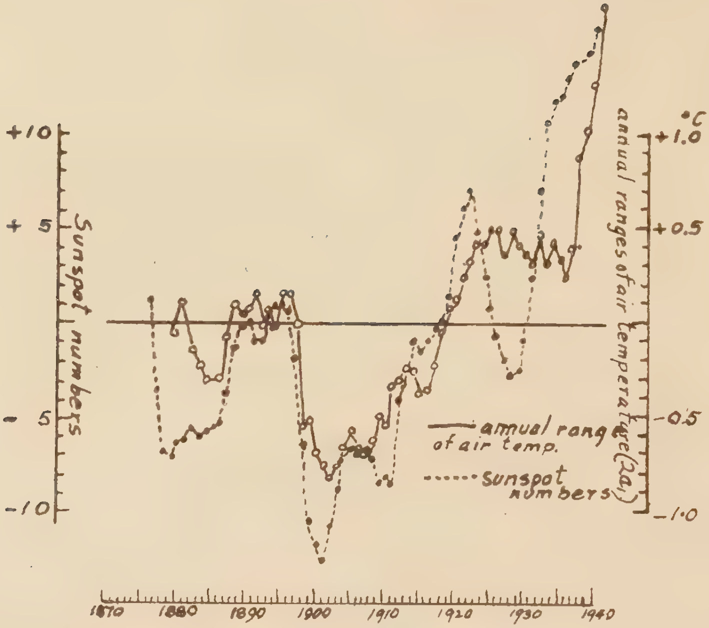


FIG. 8.—Comparison of the year running means of the annual ranges of air temperature at Hakodate with those of sunspot numbers

H. H. Clayton(7) indicated that during periods of high sunspot activity the pressure is lower in low latitudes and higher in high latitudes, and during periods of low activity higher and lower respectively. I. I. Schell(8) has recently verified the above-mentioned indications. It may not be incorrect to conclude that the global pressure distribution —that is to say, the intensities of general circulations on the earth— is actually influenced by the sun's activity in itself.

As shown in Fig. 8, comparison between the eleven-year running mean of the annual ranges of air temperatures at Hakodate, which has the oldest history of meteorological observation in Japan, and the eleven-year running mean of sunspot numbers proves a surprising accord between terrestrial phenomena and astronomical factors.

In my opinion, as the motive power for secular climatic change solar activity in itself ought to be regarded as constituting the most possible factor, if not the sole. But it is a mistake, as has often been attempted, to link solar activity directly to climatic factors at all places, for, as the intensity of the general circulation of atmosphere on the earth rises or falls according to change in the solar activity and as the climatic factors at various places change under the influence of the general circulation of atmosphere, for instance, it happens that the amount of precipitation increases in some places and decreases in other places. As will be seen from the following Table II, the secular change in the amount of precipitation in summer at Hushiki and Gifu, in central Japan, and those at Nemuro, in Hokkaido, are going on inversely.

5. REMARKS

I have presented my conclusion with the reference to the secular change of climate in Japan, attempting to make clear the controlling factors of this change. The problem may be very important related with "Weather Forecast." I wish to express my deep thanks to Dr. K. Wadati, Director of Central Meteorological Observatory of Japan, who extended me a great deal of kind help.

REFERENCES

(1) A. WAGNER: Untersuchung der sakularen Anderung der Jahresschwankung der Temperature in Europe. *Gerl. Beitr. Z. Geophys*, 20, 134, 1928.

(2) H. ARAKAWA: Is the Climate of Japan Changing? *Journal of the Meteorological Society of Japan*, 14, 425, 1936.

(3) ———— Increasing Temperature in Large Developing Cities. *Gerl. Beitr. Z. Geophys*, 50, 3, 1937.

(4) K. TAKAHASHI: On Various Methods for Forecasting Courses and Speeds of Typhoons. *Journal of the Meteorological Society of Japan*, 17, 1939.

(5) A. WAGNER: Untersuchung der Schwankungen der allgemeinen Zirkulation. *Geogr. Annalar.*, 1929, s. 33.

(6) R. SCHERHAG: Die Zunahme atmosphärischen Zirkulation in den letzten 25 Jahren. *Ann. d. Hydr.*, 1936, s. 96.

(7) CLAYTON, H. H.: Solar Activity and Long Period Weather Changes. *Smith. Misc. Coll. V*, 78, 1926.

(8) I. I. SCHELL: The Sun's Spottedness as a Possible Factor in Terrestrial Pressures. *The Bull. of A.M.S.*, Vol. 24, March, 1943, No. 3.

TABLE I—CHANGE OF ANNUAL RANGES OF AIR TEMPERATURES
(Deviation from the mean in ° c.)

Place.	Kagoshima(1).	Hushiki(2).	Miyako(3).	Hakodate(4).
Period—				
1886–1895	0·04	−0·16	−0·08	−0·20
1896–1905	−1·30	−0·90	−1·12	−1·12
1906–1915	−0·76	−0·62	−0·81	−0·48
1916–1925	0·58	0·48	0·44	0·08
1926–1935	0·50	0·18	0·20	0·18
1936–1946*	0·89	1·16	1·35	1·72
Mean ..	19·68	23·30	22·17	23·41

NOTE.—(1) 31° 34′ N., 130° 33′ E.
(2) 36° 47′ N., 137° 03′ E.
(3) 30° 38′ N., 141° 59′ E.
(4) 41° 47′ N., 140° 43′ E.

* Mean of eleven years.

TABLE II—AMOUNT OF PRECIPITATION DURING SUMMER (MAY–SEPTEMBER)
(Deviation from the mean in mm.)

Place.	Middle Part of Japan Proper.		Hokkaido.
	Gifu(1).	Hushiki(2).	Nemuro(3).
Period—			
1886–1895	− 64·34	− 95·43	+ 27·97
1896–1905	+285·33	+139·81	− 60·58
1906–1915	+ 4·23	+ 61·87	− 17·24
1916–1925	+ 54·73	− 3·49	+ 6·80
1926–1935	−158·73	− 40·81	+ 36·38
1936 1946*	−121·71	− 61·82	+ 6·64
Mean	1,140·08	791·11	525·39

NOTE.—(1) 35° 24′ N., 136° 46′ E.
(2) 36° 47′ N., 137° 03′ E.
(3) 43° 20′ N., 145° 35′ E.

* Mean of eleven years.

THE SEVEN HUNDRED YEAR PERIOD IN THE CLIMATE AND THE AURORA BOREALIS IN JAPAN

By Hideo Nishioka, Keio University, Tokyo

In 1935 Professor Shida, of the Kyoto University, first brought the 700-year wave of climatic change to light on the annular rings of what we call BENIHI, a kind of cypress about 1,050 years old which grows on Mount Ari-san, Formosa. It was, however, not clear whether this wave existed or not in Japan proper. In 1946 I received a report on the annular rings of a Japanese cypress of about 810 years' growth at Nagano Prefecture, which was measured by Mr. K. Yamazawa, and also I have measured the annular rings of old columns of Horyu-ji Temple, Nara Prefecture, and of old cedar on Mount Koya, Wakayama Prefecture, of old Zalkova acuminate at Utsunomiya City, Tochigi Prefecture, and so on.

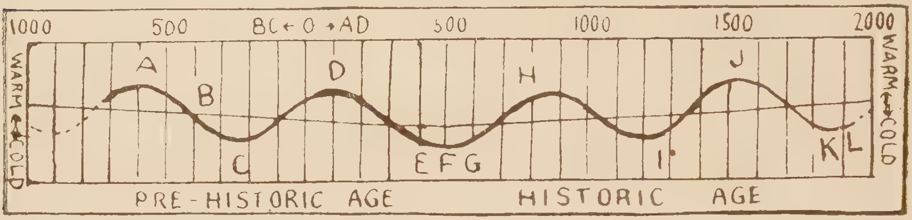


Fig. 1.—The wave of 700 year periodic change of climate in Japan

According to these measurements, the fact that a 700-year wave definitely exists in Japan has been discovered. It was, however, about two centuries behind that of Formosa—that is, the peak of the wave means the warm periods in Formosa occur in the tenth century and the seventeenth, but in Japan it is in the ninth and the fifteenth. This difference—viz., about two centuries—between the southern and northern districts will suggest some secrets which probably have relation to the fundamental reasons for both of the 700-year climatic changes. At any rate, it is beyond doubt that the 700-year wave of climatic change has occurred not only in Formosa, but in Japan. I therefore continued to pursue further research in this climatic phenomenon. Such a great change of climate marked on annular rings must bring many other historic proofs, and I could fortunately find several points of evidence in many classics, in archæological discoveries and from botanical and zoological points of view, all of which are shown on the diagram of Fig. 1 and included in its explanation.

(A) Shell-fishes (*Anadara granosa* Linne and *Sanguinolaria olivacea* Jay) and fishes (*Muraenesox cinereus* Forskal, *Tylosurus anastomella* Cuvier and Valenciennes and *Taius tumifrons* Temminck and Schlegal) living in warmer water than there is at present in Tokyo Bay were taken by the Stone age people for sustenance and formed the shell-mounds of Shimogumi, Shimokuchi, Kayama, Moroiso in Kanagawa Prefecture and other places.

(B) The lower shell-stratum of Yoshii and Orimoto shell-mounds in Kanagawa Prefecture contained many *Anadara granosa* Linne, but in the upper stratum there are no traces or very few of them. These facts indicate that the climate and the sea-water dropped in temperature from a previous warmer period.

(C) We cannot find shell-fish such as *Anadara granosa* Linne, but shell-fishes (*Natica janthostoma* Deshayes, *Mactra sachalinensis* Schrenck, *Cancellaria condulifora* Sowerby, *Pecten laqueatus* Sowerby, *Panope japonica* Adams, and *Neptune arthritica* Bernardi) living in cold currents were discovered from shell-mounds such as Takakuneda, Miyadaira, Sakura, and Komatsugawa in Ibaragi Prefecture.

(D) The temperature of the climate and sea-water changes again and becomes warm, and *Anadara granosa* Linne are found in the Fumigaoka shell-mound, Kanagawa Prefecture, the Kaminumabe shell-mound in Tokyo, &c.

(E) Shell-fishes living in cold water were taken again from the shell-mounds of Kasori, Ichinomiya, and Ishigamidai in Chiba Prefecture, which, from the archæological point of view, chronologically belonged to a later type of shell-mound in Japan.

(F) Some special kinds of human clay-doll which seemed to be wearing snow-goggles like Eskimos or Siberians to protect their eyes from glare were found from ancient sites in the northern provinces of Japan.

(G) Horse-chestnuts were excavated from many ancient sites. There are none of such plants existing in those places at present. We can see these plants in cooler places, such as in high mountains or in the northern provinces.

(H) According to the poems in "Manyo-syu," flowering season of the cherry trees was seen about a week earlier than nowadays.

(I) According to the "Taiheiki," Vol. 5, Daito-no-miya, an Imperial Prince, ate rice-gruel containing horse-chestnuts in the mountains, Nara Prefecture, where this kind of nut at present is hard to get.

(J) "Tosha-Shinko-ki" records that Lake Suwa, Nagano Prefecture, did not freeze even in the winter for eight consecutive years from 1511 till 1518. The cherry blossoms bloomed earlier than it does now.

(K) "Tonegawa-zushi" (1858) and "Kii-no-kuni Meisho-zue" (1851) mention and sketch these facts—namely, that sea-lions came down to the south even to the coast of Chiba Prefecture all the year, and to some islands of Wakayama Prefecture in the winter season. According to "Setsu-yo-kikan," the water of all rivers at Osaka Province became ice in the winters of 1813, 1822, and 1823.

(L) The modern atmospheric temperature not only of Tokyo, but of every part of Japan, is becoming higher than in the past, according to the meteorological observations during this century.

Then why does the seven hundred year periodicity of climatic change happen? This is a very interesting problem, and I have found recently one of the keys to give a solution to it. Since the seventh century we find fifty-two records of the appearance of Aurora Borealis (northern lights) in Japan in our old documents such as "Nihon-shoki," "Azuma-kagami," &c. These records are shown in the following table :—

LIST OF AURORA BOREALIS IN JAPAN

No.	Date.	Location.	No.	Date.	Location.
1	2 Jan., 621	Nara.	27	Jan., 1500	Kyoto.
2	21 Sept., 683	Every part.	28	18 Mar., 1582	Kyoto.
3	14 Aug., 839	Kyoto.	29	14 Mar., 1587	Kyoto.
4	25 April, 843	Kyoto.	30	7 Sept., 1635	Tokyo, Osaka, &c.
5	— June, 939	Kyoto.	31	Summer, autumn, winter, 1637	Tokyo, Kyoto, &c.
6	29 Mar., 1098	Kyoto.	32	— July, 1656	Tokyo.
7	29 July, 1119	Kyoto.	33	27 Oct., 1673	Kyoto.
8	19 Aug., 1150	Kyoto.	34	23 Dec., 1693	Ishikawa.
9	15 Oct., 1150	Kyoto.	35	11 Nov., 1726	Kyoto.
10	17 July, 1152	Kyoto.	36	15 Feb., 1730	Shiga.
11	13 Dec., 1170	Kyoto.	37	18 Dec., 1737	Tokyo, Kyoto, &c.
12	12 Dec., 1176	Kyoto.	38	17 Sept., 1770	Every part.
13	21 Dec., 1177	Kyoto.	39	25 Sept., 1770	Kyoto.
14	26 Dec., 1202	Kyoto.	40	12 Oct., 1771	Kyoto.
15	28 Feb., 1204	Kyoto.	41	6 Jan., 1781	Chiba.
16	27 Jan., 1205	Kyoto.	42	1 Mar., 1786	Nagoya.
17	8 Sept., 1227	Kamakura.	43	22 Sept., 1810	Tohoku
18	24 Mar., 1241	Kamakura.	44	24 Sept., 1822	Osaka.
19	17 Aug., 1247	Kyoto.	45	26 Nov., 1855	Osaka.
20	7 Aug., 1363	Kyoto.	46	2 Sept., 1859	Wakayama.
21	4 Nov., 1370	Kyoto.	47	4, 6 Feb., 1872	Shimane, Shizuoka.
22	3 Dec., 1370	Kyoto.	48	25 Sept., 1908	Ehime.
23	— Oct., 1371	Kyoto.	49	18 Oct., 1928	Sapporo.
24	21 Sept., 1440	Kansai, Aizu.	50	22, 26 Jan., 1938	Iwate.
25	23 Aug., 1455	Kyoto.	51	31 Mar., 1940	Rishiri.
26	15 Oct., 1486	Kyoto.	52	1 Mar., 1941	Anbetsu.

The monthly frequency of the aurora in Japan bears a resemblance to that of the auroræ which have been observed in other countries—Norway, Sweden, Denmark, and so on (Fig. 2). It is already known that the aurora increases and decreases its number of appearances every eleven years in accordance with the periodicity of the sun-spots. But now I have found that the frequency of the aurora in Japan has some relation to her 700-year periodic change of climate—that is to say, most of the auroræ have been sighted in the century of colder period, and that in warmer period there are few or none. I have also proved that this tendency is even more conspicious in Korea (Fig. 3). Unfortunately, we cannot get the records of the auroræ in Korea documents except during the period from the eleventh to the seventeenth century. In these records, however, are counted up two hundred and three auroræ. At any rate, it is very interesting to know that there exists a definite connection between the frequency of the aurora and the 700-year periodic change of climate in Japan. Because the aurora appears as the result of the influences of electrons from the sun upon the magnetic fields of north and south of the earth in the upper region of the atmosphere, the appearance of the aurora has a close connection with that of the sun-spots as already known. And so the 700-year periodic change of climate may also be due to some influences caused by the changes in the solar activity. The fact that the frequency of the aurora in Japan has similar periodicity with the climate will provide a serious subject to study on this problem.

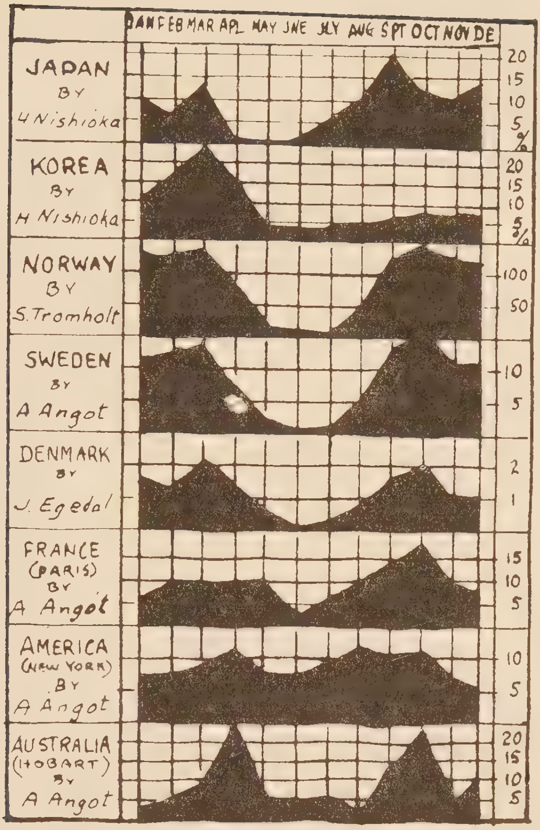


FIG. 2.—Comparison of monthly frequency of Aurora

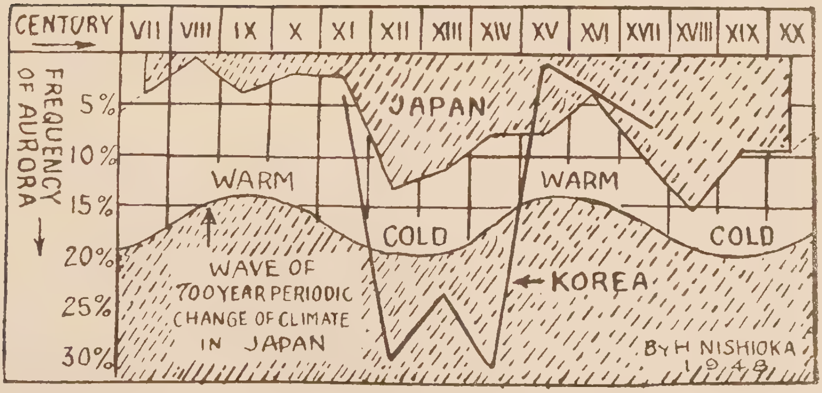


FIG. 3.—Frequency of Aurora in Japan and Korea

THE ARID BOUNDARY IN EASTERN ASIA

By Eiichiro Fukui, Japan

In order to consider the effects of precipitation upon practical problems the absolute amount of precipitation alone is not satisfactory. Especially from the agricultural and pedological point of view, precipitation excess or precipitation minus evaporation has most significance. On the other hand, the evaporation is remarkably influenced by the temperature, so that the precipitation and the temperature are the most important factors to determine the boundary between the arid and humid regions. For this purpose many formulæ involving the precipitation and temperature have been found. Although these formulæ apparently are of different types, we can transform them into the same functional expression.

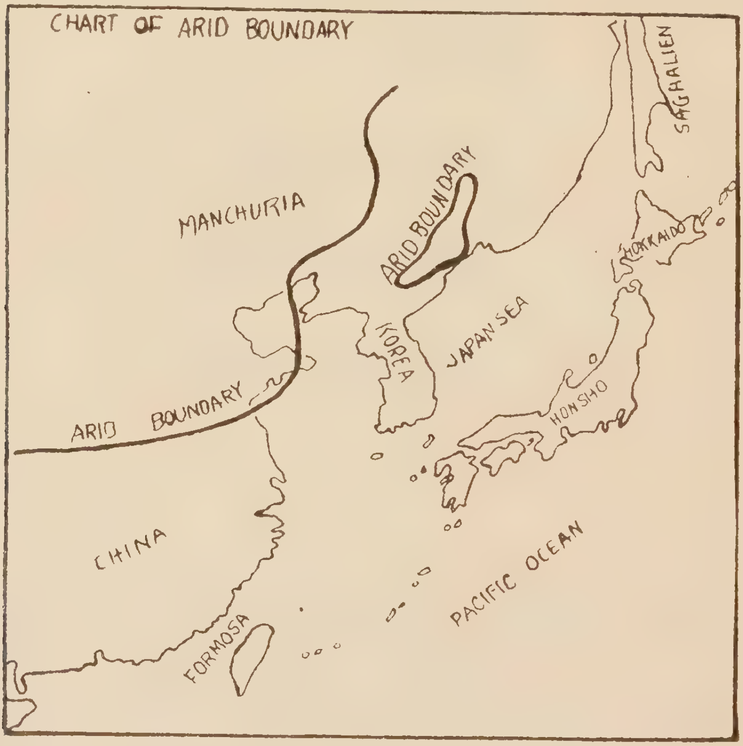


CHART OF ARID BOUNDARY
MANCHURIA
ARID BOUNDARY
ARID BOUNDARY
KOREA
JAPAN SEA
SAGHALIEN
HOKKAIDO
HONSHO
CHINA
FORMOSA
PACIFIC OCEAN

W. Köppen expressed the dry limit by the precipitation and temperature. Annual precipitation r (cm.) on the boundary line which separates the stepp climate from the humid climate is given by the empirical formulæ

$$r = 2\,(t + a)$$

where t is the annual mean temperature at the station and a is a numerical constant.

Similarly, the annual precipitation r on the boundary line between the stepp and desert climate is given by

$$r = t + a$$

F. R. Falkner (1938), based on climatological study in Africa, expressed the arid boundary by the following formulæ

$$r - t = 12 \text{ or } r = t + 12$$

This is the same form as Köppen's.

Emm. de Martonne's aridity index D, the most famous formula, is given by

$$D = \frac{P}{t + 10}$$

where P is the annual precipitation (millimetre), and t the annual mean temperature (°c.).

R. Rang's rain-factor ("Regenfaktor"), based on the pedological point of view, is also the similar form

$$D^1 = \frac{P}{t}$$

These two formulæ are generally expressed by

$$D = \frac{P}{t + \beta}$$

and D^1 is considered to be a special case when $\beta = 0$.

Martonne considered that the outer limits of land utilization and agriculture coincide with the line which connects the points where D is 20.

Hence if we express P by centimetres instead of millimetres, the upper formula becomes

$$P = 2\,(t + \beta)$$

which is the same as Köppen's.

C. W. Thornthwaite called the ratio of precipitation to evaporation by the name of "P–E ratio" and empirically expressed it by

$$\frac{P}{E} = 11{\cdot}5 \left(\frac{P}{F - 10}\right)^{\frac{10}{9}}.$$

where P is the annual precipitation (inch) and F the annual mean temperature (°F.).

If we choose the unit of millimetre and centigrade instead of inch and fahrenheit respectively

$$\frac{P}{E} = 0{\cdot}17 \left(\frac{P}{t + 12{\cdot}2}\right)^{\frac{10}{9}}$$

Now we define the dry limit where the annual amount of precipitation equals the annual evaporation, or P–E ratio is 1·0, the upper formulæ becomes

$$P = 3{\cdot}6\,(t + 12{\cdot}2)$$

This is also similar in form to Köppen's, except that the numerical constants differ a little.

Hence the formula devised by many authorities reduce to the same form. But the numerical constants must be different with respect to the individual regions and not unique in the wide area of the world.

Especially in eastern Asia, the climatological conditions are very different from other continents and the above-mentioned formulæ are not applicable by themselves.

In eastern Asia evaporation is observed at few stations, and ample material is not obtainable. Now the observational data are collected as much as possible in Japan, Manchuria, China, and East Indies. Through previous study we ascertain that the annual evaporation is related not only to the temperature, but also to the amount of precipitation, but the mutual correlation is not the same with respect to the individual regions. So we can express the annual amount of evaporation E by the linear function of temperature t and precipitation P.

$$E=a+bt-cP$$

The constants a, b, and c are determined by the method of least squares in each region, and the following results are obtained.

Japan : $E=790+32{\cdot}8t-0{\cdot}03P$
Manchuria : $E=1375+50{\cdot}7t-0{\cdot}09P$
China: $E=3506-117{\cdot}7t-0{\cdot}40P$
East Indies : $E=449+29t-0{\cdot}13P$

Theoretically the arid boundary may be chosen where the amount of annual evaporation equals that of the precipitation. But practically the amount of evaporation measured by instruments in general use in Japan and other countries is too much as compared with the real value. Sometimes it reaches twice the evaporation from the field surface. Moreover, a part of rain-water runs down into the ground and it is clear that the precipitation equal to evaporation does not give the arid boundary. However, as these details are not completely known, I assumed temporarily that the arid boundary is located where the annual amount of precipitation is half of the annual evaporation. Only in the East Indies, where the Wild's atmometer is used, the boundary is taken where the annual amount of precipitation is equal to that of evaporation. Thus the annual amount of precipitation P on the arid boundary line is given by the following formulæ.

Japan : $P=387+15{\cdot}8t$
Manchuria : $P=206+18{\cdot}5t$
China : $P=1463-49t$
East Indies : $P=397+25{\cdot}6t$

So, if the actual amount of precipitation at any place is larger than the calculated value P, it belongs to the humid climate and *vice versa.*

For example, the calculated value P in the East Indies is 1,040 mm., and actually no station belongs to arid climate.

The whole of Japan also belongs to humid climate, while a part of Manchuria and China represents arid climate. The boundary line is shown in the map. The northern half of China and the eastern part of Manchurian mountainland belong to arid region. Actually this boundary line agrees well with the distribution of plants and geographical landscape—for example, the northern limit of rice-cultivation.

SYMPOSIUM ON RESEARCH NEEDS AND TECHNIQUES IN PACIFIC METEOROLOGY

CONVECTION CURRENTS IN THE ATMOSPHERE OVER A SOURCE OF HEAT

By Sir GEOFFREY TAYLOR, Cambridge University

[*Abstract*]

This paper shows how the heat in a vertical convection column spreads out and how high it penetrates when a given supply of heat is released into an atmosphere with a given vertical distribution of temperature.

The studies were carried out partly in connection with the dissipation of fogs on aerodromes by supplying heat, and partly during work on the atomic bomb at Los Alamos.

DISCUSSION

Mr. Hutchings pointed out that Sir Geoffrey's results would be very useful in the problems of orchard heating for frost protection, while Dr. Spilhaus pointed out that they could also be very useful in the problems of waste disposal.

Mr. Simpson gave an interesting discussion on aeroplane flights over the volcanoes of Hawaii, and the results obtained in this way for the temperature distribution seemed to agree qualitatively with Sir Geoffrey's conclusions.

Mr. Priestley remarked that Sir Geoffrey's analysis showed the excellent results that could often be obtained by very simple methods.

CONTROLLED ALTITUDE BALLOONS AND VERTICAL MOTION IN THE HIGH ATMOSPHERE

By ATHELSTAN F. SPILHAUS, University of Minnesota

[*Abstract*]

Flights with high altitude balloons controlled so as to fly at constant pressure surfaces are described, and certain features of the trajectories of the balloons are discussed.

During several flights it was noticed that the barographs carried by the balloons recorded oscillations with periods between approximately one and ten minutes. Since these periodic height variations cannot be attributed to the mechanism maintaining the level of the balloon, they must be attributed to real oscillations of the atmosphere. The lengths of the observed periods agree very closely with those computed from the observed lapse rates of temperature. The vertical velocities associated with these oscillations range up to 1,000 ft. per minute.

DISCUSSION

In answer to a question by Mr. Priestley, Dr. Spilhaus said that at present the control was not sensitive enough to measure very accurately small vertical velocity, such as, for example, that due to subsidence.

One point of interest mentioned by Dr. Spilhaus was that the trajectories of the balloons do not agree very closely with the trajectories computed from the geostrophic winds. The deviation was always towards regions of lowest pressure. Dr. Spilhaus mentioned that oscillations observed in the pressure-recording apparatus carried by the balloon had been observed on a number of occasions, but it is not yet certain whether they are oscillations of the atmosphere or of the balloon.

GLOBAL TRANSPORT OF HEAT AND MOMENTUM

By C. H. B. Priestley, C.S.I.R., Melbourne, Australia

[*Abstract*]

Global transport of mass, heat, water vapour, momentum, vorticity, &c., are irregular processes whose irregularities are on the scale of cyclonic and anticyclonic disturbances. A quantitative study of these transports is required before we can approach a full understanding of the average distribution of these elements, and, further, of the variation in distribution with season and differences between one year and another. Probably the first part of the problem to be faced relates to the mean distribution with latitude. In this the meridional transport is the significant quantity. Within any latitude zone there are processes occurring which left to themselves, would effect a more or less continuous loss or gain of the elements concerned—for example, a high-latitude zone would cool in virtue of an excess of outgoing over incoming radiation, a zone in the westerlies would slow down through surface friction, and so on. Relative to the magnitude of the non-conservative influences, the mean conditions in any latitude zone change, if at all, very slowly. In a study of the mean latitudinal distribution it may be adopted as a working principle that the loss or gain of heat, momentum, &c., is compensated by transports from adjacent zones. In the case of mass, where no non-conservative process is involved, the mean transport across any latitude must be zero.

The technique for evaluating these transports has been described elsewhere (see references), together with a discussion of the results obtained from upper-air data at Larkhill covering a period of two years. Further evaluations have been made from a year's observations at Norfolk Island (29° S. latitude) and some isolated two-monthly periods at various stations in or near 10° latitude in the Western Pacific Region. The wind data available did not go above 400 mb. with sufficient regularity to permit evaluations above that level; so the results are indicative rather than quantitatively exact. Certain tentative conclusions may be drawn :—

(1) A reversal in the troposphere of the eddy-flux of heat, a typical feature at Larkhill, is evidenced also at Norfolk Island.

(2) The percentage of the total eddy-flux of heat which takes place in latent form increases from about 50 per cent. at Larkhill to about 70 per cent. in latitude 10°.

(3) Great care must be taken to obtain representative data in low latitudes, and more than one ascent per day may be necessary for an accurate evaluation.

(4) The mean eddy-flux of momentum found for the year at Norfolk Island was $0{\cdot}16 \times 10^8$ dynes/cm., in such a sense as to exert an eastward pull on the tropical zone. From this result the eddy-flux of momentum, or total Reynolds' stress across latitude 30°, does not appear to maintain the surface easterlies on the equatorial side nor the wide belt of westerlies to poleward. For the maintenance of these mean zonal flows we require a far larger poleward flow of westerly momentum across this critical latitude, and this momentum transfer must inhere in the mean flow pattern. A toroidal circulation, with poleward component of flow at the level of maximum wind (jet stream), would supply a transfer in the right sense. The danger of the geostrophic wind assumption in these studies is to be emphasized.

(5) The total eddy-flows of heat in all these latitudes are of the right sign and magnitude to compensate for the radiation losses and gains. But since mean toroidal flows, which are necessary for the mass and momentum balance, must bring about a large net flow of heat (see references), it is clear that the mean temperature and moisture distributions are not to be explained in terms of eddy-transport alone.

REFERENCES

Priestley, C. H. B. : *U.G.G.I.* (Oslo), 1948.
— —— *Quart. Jour. Roy. Met. Soc.*, Jan., 1949.

DISCUSSION

In reply to a question by Mr. Andrew Thomson as to whether stations on meridians or on parallels are more useful, Mr. Priestley replied that, ideally, both were required, but in the event of only a few stations being available those on different parallels of latitude would be most useful.

In answer to a question by Mr. Hutchings, Mr. Priestley said that the unavoidable slight errors in temperature given by radiosonde data were not a serious limitation in this work. What was required was continuity in time.

NEW METEOROLOGICAL INSTRUMENTS

By ANDREW THOMSON, Controller, Meteorological Service of Canada

[*Abstract*]

1. The Meteorological Service of Canada has recently developed the Gill hydrogen generator which will produce about 100 cu. ft. of hydrogen in about eight minutes at a maximum pressure of 3 lbs. per sq. in.

The process employed is to add water at a controlled rate to a mixture of flake caustic soda and aluminium turnings. The reaction produces much heat and steam, which is quickly removed by passing the gases through boiler tubes filled with a cooling solution. After the reaction is completed the residue can be washed out easily, and within two minutes the generator can be made ready for generating another charge of hydrogen.

2. There has also been developed (along the lines of the Robitsch pyrheliometer) a solar radiation instrument which will record mechanically the total amount of solar radiation falling on a horizontal surface. A

maximum discrepancy of 5 per cent. has been found between Eppley instruments and the new pyrheliometer, and this amount can be reduced while sealing the record. A seven days' record is obtained on a chart placed on the conventional spring-driven drums revolving once a week.

DISCUSSION

In reply to a question by Mr. Ewing, Dr. Thomson said that the hydrogen generating instrument could probably be adapted for use with ferro-silicon instead of aluminium. With regard to the pyrheliometer, Dr. Spilhaus suggested that it would be advantageous if it could be adapted to stand the rolling that takes place on weather ships which at present affects the accuracy of observations taken aboard these vessels.

With regard to observations in the Arctic, Dr. Priestley raised the question of how one might distinguish between falling and drifting snow, and in reply Dr. Thomson said that no practical method had been found of making this distinction.

AUSTRALIAN EXPERIMENTS IN ARTIFICIAL RAIN FORMATION

By E. BOWEN, C.S.I.R., Australia

EXPERIMENTS on the artificial production of rain by the dry-ice process have been conducted by C.S.I.R.'s Division of Radiophysics since January, 1947. The main purpose of the investigation is to obtain a proper understanding of the physical processes which occur when dry ice is dropped into subfreezing clouds.

The experiments are carried out by C.S.I.R. personnel in aircraft of the Royal Australian Air Force whenever suitable clouds exist in the vicinity of Sydney. These are nearly always found within about 200 miles, mostly over land, but sometimes over the sea. The majority of the tests have been made with cumulus cloud, as this is the type most frequently encountered in New South Wales, and it has been found by experience that deep cumulus clouds give the heaviest precipitation. Experiments have also been made with shallow stratus and alto-cumulus cloud, and although precipitation is often induced, in few of these cases has it reached the ground. The quantity of dry ice used has varied, from 50 lb. to 300 lb. dispensed at a rate from 10 lb. to 30 lb. per mile but there is no evidence to show whether different quantities produce different effects. The dry ice is broken into fragments, the majority of which have an effective diameter of about 1 cm.

Before an experiment is performed, measurements are made of the clear air temperature and humidity in the vicinity of the selected cloud and careful observation made to ensure it does not already contain large drops or ice particles. In some cases flights are made through the cloud before and after seeding with dry ice and observation made of the type of drops and particles encountered and of the vertical air velocity. Visual and photographic observations are made from outside the cloud, and in some cases they are supplemented by 10 cm. and 25 cm. air-borne and ground radar sets.

NUMBER OF SIGNIFICANT EXPERIMENTS

Thirty-eight complete experiments were made up to 25th August, 1948. In the majority of these rain was observed to fall from the selected cloud after it had been seeded with dry ice. The most convincing proof that this was brought about by the dry ice is the great number of occasions on which the top of the cloud was observed to change from water drops to ice particles and on which precipitation fell from the cloud shortly after seeding, while similar clouds in the vicinity showed no such change.

A full description of the experiments and of the main results is being published shortly in papers by Squires and Smith in the *Australian Journal of Scientific Research.*

DEDUCTIONS FROM THE OBSERVATIONS

In making deductions from the experiments, eighteen of them have been rejected either because the prevailing weather conditions made observation difficult or because there was some doubt whether the rain which fell was in fact caused by the seeding process. In the remaining twenty the observations were adequate and the conditions were sufficiently stable and clear-cut for the results to be known with certainty. The main deductions which can be drawn from these limited data are as follows :—

(*a*) *The Effect of Cloud Temperature.*—It is found that the chances of successfully producing rain increase as the temperature of the top of the seeded cloud decreases below zero. Of the twenty tests being considered, precipitation was produced in fifteen cases and quite definitely not produced in five, as detailed in the table.

Cloud-top Temperature.	Positive. Result.	Negative. Result.	Percentage of Positive Results.
0 to − 3	2	2	50
− 4 to − 7	3	2	60
− 8 to −11	5	0	100
−12 to −15	5	0	100
−16 to −19	0	0	..
−20 to −23	0	1	0
Total	15	5	75

Four of the five failures occurred between 0 and −8° C. All ten experiments between — 8° and — 16° C. were successful, and there was a single unexplained failure at −20° C.

Although temperature has been chosen as a convenient parameter for estimating the probability of success it is obvious that the growth of ice nuclei in the cloud is influenced by a number of other factors, including the degree of supersaturation, the total water content, and the time for which the nuclei are exposed. It is not suggested that temperature is the sole controlling factor. Any of the above either individually or collectively might influence success or failure.

(*b*) *Interval Between Dropping of Dry Ice and the Appearance of Rain.* —In each of the experiments careful observation was made of the time-interval between dropping the dry ice and the first appearance of precipitation or rain from the base of the cloud. If this is plotted against cloud thickness, there is a distinct tendency for the interval to increase with increasing cloud depth. It appears that the time-interval is in two parts—a gestation time of about ten minutes and an additional time which is a function of cloud thickness and might therefore be related to the rate of fall of precipitation within the cloud.

(*c*) Rough observations have also been made of the intensity of precipitation and when plotted against cloud thickness it is found, as one might expect, that there is a distinct tendency for rain intensity to increase with cloud thickness.

Conclusions

The number of occasions on which the top of cumulus clouds have changed from water drops to ice particles and on which precipitation has been observed to fall from the base of the cloud after being seeded with dry ice while similar clouds in the vicinity remain unchanged is convincing proof that rain can be induced to fall artificially. The chances of success are found to improve with decreasing temperature of the cloud top and are greatest at temperatures between $-8°$ and $-16°$ c. It appears that the interval between seeding and precipation from the base of the cloud is a function of cloud thickness and that the intensity of precipitation is also a function of this thickness.

Discussion

Mr. Mordy, of the Pineapple Research Institute of Hawaii, gave an account of the experiments being conducted by the Institute, and described the techniques that had been developed. Mr. Mordy urged caution in the interpretation of these results which were in the process of evaluation.

Mr. Andrew Thomson, of Canada, said that in Canada many similar experiments had been carried out, particularly with regard to the production of snowfall. He said that in clouds at temperatures below freezing rainfall always resulted, while clouds at temperatures above freezing gave no rain. The maximum amount of rainfall measured was in the vicinity of two-tenths of an inch.

Some experiments had also been made in Canada using silver iodide instead of dry ice, but it was found that the silver iodide was not nearly so effective in the free air as it had been found to be in experimental cloud chambers. Numerous cases had occurred also of dry ice causing the formation of clouds in clear air and the production of holes in strato-cumulus clouds.

Mr. Simpson, U.S. Weather Bureau, Hawaii, described similar experiments in the United States and stated that although results had been rather negative up to the present, the experiments were still being actively continued.

In answer to a question by Dr. R. G. Simmers, Mr. Mordy stated that in Hawaii most of the experiments had been on geographically persistent clouds.

In reply to a question by Mr. Unwin, Dr. Bowen stated that there were no obvious reasons for the few unsuccessful cases that had occurred in his experiments ; in fact, the appearance of the cloud in the successful cases had not differed materially from the cloud in the unsuccessful tests. In reply to another question he said that there was a possibility of seeding the cumulus type of cloud from below by making use of the up-currents that are always present in these clouds. He believed the experiment had been tried, but this method was not used in Australia.

THE BEHAVIOUR OF WATER IN ITS VARIOUS PHASES AT LOW TEMPERATURES AND ITS APPLICATION TO METEOROLOGY

[*Abstract*]

By B. M. Cwilong, Victoria University College

This paper describes in some detail a series of experiments on the properties of water, particularly with regard to phenomena of condensation. Various different characteristics possessed by certain metallic surfaces and their effects on the condensation of water vapour are discussed. The properties of silver iodide are also discussed, and some insight is given into the effectiveness of these nuclei in the seeding of clouds for the production of rain.

A FORM OF POTENTIAL GRADIENT SONDE APPARATUS

By K. Kreielsheimer, Auckland University College

[*Abstract*]

The method of modifying the Bureau of Standards' Radio-Meteorograph for the measurement of the potential gradient in the atmosphere is explained. The method is based on the current due to point-discharge under the influence of the electrostatic field surrounding the earth.

Various demonstrations are given to show the effect and the extensions required to the method to record both small and large gradients with sufficient accuracy. The calibration of the sonde and the factors affecting the measurements are discussed in detail.

The research is concerned particularly with the disturbed conditions due to thunderclouds and the charge distribution within these clouds.

ON THE SEGREGATION OF THE SEA-SALT COMPONENTS AND THEIR DISTRIBUTION IN THE AIR

By Ken Sugawara, Shinya Oana, and Tadashiro Koyama,
Nagoya University, Japan

[*Abstract*(1)]

It was shown that the chemical composition of the wind-borne salt from sea varies so that Ca/Cl and SO_4/Cl increase horizontally, as it recedes from sea beach towards inland, and also vertically, as we go from sea-level upwards. The horizontal variation was proved in two different ways—the one, by the comparision of the chemical analyses of more than one hundred rain samples from three different stations, differing in distance from sea, and the other, by that of the salt which

---

(1) A fuller account will be published in *Bulletin of the Chemical Society of Japan*, Vol. 22, No. 2.

was caught by pine-needles from the air. The vertical variation was shown by the comparison of three different kinds of meteorological water substances,—the ordinary rain-water from 500–1,000 m., the fog-ice from the summit of Mount Fuji (3,376 m. high), and the water of thunderstorm, originating at a height of 4–15 km.

The cause of such distribution of wind-borne salt in the air seems to lie in the partial crystallization of the wind-borne particles of sea-water by evaporation, with production of at least two kinds of daughter particles. The one, hygroscopic in nature and consisting mainly of Na, Cl, Mg, &c., is unstable and falls down earlier from the air, while the other, crystalline in nature and consisting mainly of the sulphates of Mg and especially of Ca, is stable and thus remains longer in the air.

As to the processes of the earlier falling down of the unstable components, two kinds of way were pointed out—the one the selective washing by rain, and the other the selective capturing of the unstable components by various extrusions on the earth's surface, for instances, edifices, shrubs, woods, &c.

PROGRESS OF METEOROLOGICAL INVESTIGATIONS IN JAPAN SINCE 1939

By Kiyoo Wadati, Central Meteorological Observatory, Japan

The special feature of the meteorological investigations since 1939 is the strong tendency to application in consequence of the war. Many papers have been published until the year 1941, but the number of publications began to diminish thereafter owing to the Pacific War. In 1943 the publication of papers with subjects relating to war increased temporarily, but since 1944 research activity was almost stopped until 1946. Though it is now recovering to the pre-war condition, there are many difficulties left to be overcome.

Meteorological investigations are made mainly by the scientists of the Central Meteorological Observatory and partly in the Tohoku, Tokyo, Kyoto, and Kyushu Universities, where the professorship for meteorology is established. On the other hand, the Low Temperature Research Laboratory in the Hokkaido University and agricultural experimental stations belonging to the Ministry of Agriculture and Forestry are performing meteorological studies of their concern. As the societies established for the meteorological study the following are to be mentioned: the Meteorological Society of Japan, the Marine Meteorological Society, the Agricultural Meteorological Society, and the Japan Society of Snow and Ice.

The most remarkable progress made since 1939 should be found in the project of long-range forecasting, especially that for few days. From 1939 through 1943 K. Takahashi analysed weather changes over Japan. He also studied the method to extrapolate the tracks of highs and lows a few days and showed the possibility of forecasting covering a few days. In 1940 H. Arakawa found the importance of wind aloft on the forecasting for a week, and studied statistically the variation in the atmospheric circulation. In 1943 Y. Nakata tried to extrapolate complicated variations as in daily pressure and temperature, dividing them into short and long periodic components. Since 1946 A. Fukuoka devised to analyse pressure oscillations into stationary components. Since 1943 M. Ogawara investigated the long-range forecasting by means of comparing method of similar weather charts, while T. Yazawa and others studied long-range forecasting by means of five-day mean weather charts and classification cards.

With respect to seasonal forecasting, weather stations in the Tohoku district are co-operating under M. Morita, Director of the Sendai District Central Meteorological Observatory since 1941, in relation to the bad harvest in this district. The results obtained are published in the *Journal* of the Connecting Society in the Tohoku Meteorological Organization. In these investigations, making use of periodic changes of climate and the relation between climate and drift-ice, remarkable progress has been made in the technics of forecasting, but with respect to scientific or physical basis of the method further studies are yet necessary.

Studies on lows and typhoons were made in relation to the daily weather forecasting by T. Otani, H. Fuchi, S. Ooma, N. Yamada, and K. Takahasi. In 1942 S. Syono treated the lows from the point of view of vortex. H. Arakawa (1941) and Syono (1947) discussed the instability of Siberian anticyclones.

In connection with aeronautics, a number of investigations on the upper air meteorology were made, of which special stress was laid upon the improvement of observational instruments. Since 1937 researches on radiosonde and radiotracking were made by D. Nukiyama, H. Yuasa, Y. Shirai, and K. Isono. At present the radiosonde of wave-length variation type is being used. This has been compared with the U.S. radiosonde of frequency modulation type, and it was proved that the accuracy is almost the same for both instruments. Radiosonde and radiotracking are being utilized since 1938 and 1943 respectively. Moreover, various sonde instruments for cloud observation, icing observation, &c., are constructed experimentally since 1943. In 1944 D. Nukiyama, K. Tsukamoto, and others began to establish the automatic weather station.

Concerning the aeronautics, in 1938 H. Arakawa studied the winter bad weather of Japan Sea side by radiosonde observations. Later, on the same subject, studies were made by aeroplane observations by the Army Weather Bureau. The heavy snowfall in Japan Sea side is caused by winter monsoon. Studies concerning this problem have been made during the period from 1943 to 1946 by K. Sugiyama, K. Kunii, T. Kawamoto, and others, and the importance of local front has been found as a result.

During the years from 1939 to 1944 a synthetic study of cumulonimbus was planned by the Ninth Special Committee for the Protection of Thunderbolt Damage, Japan Society for the Promotion of Scientific Researches. In summer of these years S. Fujiwhara, D. Nukiyama, Y. Kodaira, H. Hatakeyama, S. Syono, S. Sakuraba, and others, concerning various branches of this study, were despatched to Maebashi and executed this plan. The results obtained were made public by D. Nukiyama, S. Syono, Y. Kodaira, S. Sakuraba, and others. On the other hand, M. Abe studied the development of cumulonimbus by means of moving pictures. At the time the direction-finder for atmospherics constructed by A. Kimpara was also utilized for the study. During the period 1942 through 1943 many studies were made on the weather in tropical latitudes by the forecasters despatched to those districts. The results obtained were reported by H. Fukuda, K. Hirasawa, S. Daidoji, and K. Fujita, and published, though in mimeographed copies. By these studies the following facts were revealed: (1) in the tropical latitudes the streams of air flowing out from the anticyclones in temperate latitudes form a kind of converging line with a band of cumulonimbus along it, and (2) a weak high develops over the Equator which has great influence upon the weather in the equatorial region. On the other hand, K. Uwai studied the formation of typhoons on the equatorial front, and T. Otani investigated in 1946 the mechanism and origin of rainy season in the tropics.

Concerning fog, an investigation on a large scale was made in 1944 at Hokkaido, by Y. Yoshida, K. Fukutomi, and Y. Miyake, under the leadership of U. Nakaya, of the Hokkaido University. By this, precise measurement of meteorological elements were made ascending to the height of 1,200 m. above the ground by means of a big captive balloon. The state of temperature inversion, diameter, and number of fog particles with their absorbing power for the solar radiation, &c., were investigated and many important results were obtained. This investigation had for its object the artificial dissipation of fog. Also in the same year observations of radiation fog were made by S. Sakuraba, Y. Matsudaira, and Y. Shibata, and a part of results thereby obtained were reported by Sakuraba.

In relation to the explanation of visibility, aeroplane icing, and precipitation mechanism, investigations on the hydrometeors as rain, snow, fog, and dust particles were made during the period from 1940 to 1943 by Y. Takahasi, K. Ito, I. Imai, and others. In theoretical aspects G. Yamamoto studied evaporation adopting the theory of boundary layer in 1941, and T. Hagiwara treated the evaporation from rain-drops since 1946.

In 1941 and 1942 U. Nakaya studied the " frost heaving " of the ground, while in 1941 experimental studies of artificial avalanches were made near the Shimizu Pass in the Mikuni Mountain Range by the Ministry of Transportation. In addition to this, R. Saito investigated various properties of snow on the ground. The studies on these subjects were mainly published in the journal *Seppyo (The Ice and Snow)*.

In 1939 and 1940 Y. Kato and T. Sato, of the Tohoku University, made an absolute measurement of insolation intensity. In 1940 and 1941 Y. Daigo, M. Nakahara, and E. Fukui studied the correlation between crops and weather, animal phenology, and the climate of Asia respectively. At the agricultural experimental stations of the Ministry of Agriculture and Forestry microclimatological studies since 1943 and studies on the noxious insects of rice were performed from the meteorological point of view. H. Hatakeyama, S. Suzuki, A. Kimpara, and T. Asada made a long study on the relation between fires and weather conditions. Owing to the results obtained by this study, fire warning based upon the weather conditions was put into practice all over the country since autumn of 1947. Also the study of K. Wadati on the air current accompanying cyclones and that of S. Syono on isallobaric winds are to be mentioned here. Moreover, there are many investigations on climatology and meteorology, of which " the World Meteorological Data," " the Meteorological Data of Eastern Asia," and " the Aeronautical Weather Charts," published by the Central Meteorological Observatory in 1942, 1943, and 1944, are regarded as representative.

The following is the list of publications which appeared in this period, most of which are in Japanese. In this list, among those publications treating the same subject, only the latest one is mentioned.

List of Publications Which Appeared in This Period

1939—

H. Arakawa : Investigation of Monsoon by Radiosonde Over Toyama City. *Report of Aerological Meteorology*, 2, 158–181.

— — Upper-air Current and the Long-range Weather Forecasting. *Weather and Climate*, 7, 444–445.

S. Ooma : On the Development of Cyclones in the Neighbourhood of Japan. *Journ. Met. Soc. Jap.*, 18, 243–256.

1941—

H. Arakawa : Statistiche Untersuchungen atmosphärischer Zirkulationsschwanchungen. *Met. Zeit.*, 5, 183–184.

——— Stability of Cyclonic Current. *Journ. Met. Soc. Jap.*, 19, 171–175.

M. Nakahara : Investigations of the Animal Phenology in Japan. *Journ. Met. Soc. Jap.*, 19, 381–387.

Y. Daigo : Studies on the Relation Between Yield of Chief Crops and Weather Factors in Japan. *Journ. Met. Soc. Jap.*, 19, 301–313.

S. Syono : Studies on Atmospheric Disturbances. *Journ. Met. Soc. Jap.*, 21, 443–449.

1943—

Y. Nakata : On the Periodic Fluctuation of Air Temperature. *Journ. Met. Soc. Jap.*, 21, 402–409.

K. Takahasi : Dynamic Climatology in Japan. *Journ. Met. Soc. Jap.*, 21, 27–37.

K. Uwai : On Equatorial Fronts in the South Seas. Restricted Report of the Meteorological Studies, 4, 1–92.

H. Arakawa : On the Invasion of Equatorial Air Mass Which is the Cause of Heavy Rain in the End of Baiu.

D. Nukiyama and S. Syono : Occurrence of Thunder and Upper-air Observations. Report of Aerological Meteorology, 6, 1–32.

S. Fujiwhara and Others : Report of Special Thunder Observation. *Memoirs of the Cent. Met. Obs. of Japan*, 21, 1–320.

H. Arakawa : Seasonal Change of Lows Originated in the Neighbourhood of Japan. *Sea and Sky*, 23, 393, 400.

S. Sakuraba : On the Energetics of Vertical Lability. *Journ. Met. Soc. Jap.*, 21, 501–505.

1944. None.

1945—

U. Nakaya and Others : Studies of Fog in Hokkaido. Technical Academy, Conference of Mobilization.

1946—

M. Ogawara : Studies on the Long-range Forecasting Based on the Statistical Method. Temporary Report of Studies, 6.

S. Sakuraba : Studies on Cumulonimbus. Temporary Report of Studies, 4.

S. Isigura : Summary of the Study on the Forecasting of Chilo Simplex's Generation. Report of the Agricultural Experimental Station of Aichi Prefecture.

M. Kato : Considerations From the Agricultural Meteorological Point of View on the Relation Between the Condition of Cultivation, and the Generations of *Chloropo Oryzella* and the Water Temperature of Irrigation. *Matsumushi*, 1.

1947—

A. Hukuoka : On the Analysis of Long-range Meteorological Phenomena Into Stationary Oscillations. *Journ. Met. Soc. Jap.*, 25, 11–24.

M. Ogawara : Stochastic Method of Forecasting. Temporary Report of Studies, 24.

S. Sakuraba : Investigation of the River Fog. Temporary Report of Studies, 28.

S. Syono : On the Mechanism of Generation of Cold Waves. Report of Geophysical Institute, Tokyo Univ.

S. Ogiwara : Evaporation of Rain Drops. *Journ. Met. Soc. Jap.*, 25, 1–11.

H. Hatakeyama : Fires and the Weather. (Monograph), pp. 112.

OCEANOGRAPHY

REPORT OF THE STANDING COMMITTEE ON OCEANOGRAPHY

REPORT BY THE CHAIRMAN OF THE INTERNATIONAL COMMITTEE ON THE OCEANOGRAPHY OF THE PACIFIC

By Thomas G. Thompson (Chairman of the Standing Committee),
University of Washington

Over a decade has passed since the present chairman of the International Committee on the Oceanography of the Pacific presented his report to the Sixth Pacific Science Congress which was held in the United States. The international committee at that time was well organized, due largely to the magnificent efforts of Dr. T. Wayland Vaughan, the previous chairman. Most of the members of this committee were chairmen of their respective national committees, and much had been done by them to promote numerous oceanographic investigations in many parts of the Pacific.

Since that time we have lived through the greatest war in history. For over six years the efforts of the scientists of the warring nations were diverted to problems of immediate military or national importance, and recently to the perplexing problems of reconstruction. This period through which we have passed has also witnessed marked tendencies for social and economic changes due to the advances in science and technology. The remarkable achievements in aviation have literally produced a shrunken world. The distance from New Zealand to North America, for example, is no longer measured in weeks, but now in hours for traversal. Seattle and Vancouver are closer to Auckland to-day than they were to New York and Montreal twenty years ago. The United Nations Organization has come into being. Within its structure are commissions vitally concerned with human progress through education and scientific research. We, gathered here and representing the scientists interested in the greatest of all the oceans, are most desirous to play a part in furthering the functions and accomplishments of the world organization by giving special attention to the Pacific.

During the years of conflict many trends in scientific thought and endeavour were catalyzed. Huge sums of money were made available for research. Programmes of investigation were planned and initiated to a degree almost undreamed a decade ago. The results of these investigations used at the time to further the subjugation of an enemy can now be applied in the cause of peace for promoting human welfare and to stimulate the acquisition of further knowledge. Scientists of various specialties as well as nationalities learned to plan and work together toward solutions of complex problems. The results obtained emphasized again the importance of team work.

Some months ago the chairman of this Committee on the Oceanography of the Pacific made attempts to reorganize his group in anticipation for the preparation of a report to the Seventh Pacific Science Congress. It was found that some of our colleagues had died, others had retired and still others were of the opinion that they were no longer in a position to speak with authority for their countries or their organizations. The prospects were rather discouraging. However, after correspondence with Dr. Gilbert Archey, Secretary-general of this Congress, a plan of operation was initiated, and I am most grateful to Dr. Archey for his advice and suggestions.

There was considerable exchange of correspondence with various governmental authorities, research organizations, and individual scientists in the several countries. Many of the letters received in reply told much the same story—namely, reorganization still in progress to meet peacetime conditions, difficulty of securing equipment and personnel, unsettled conditions, extensive programmes for oceanographic research still in the planning stage, and generally the hopeful anticipation for funds.

However, excellent reports were received from many, and these are given in the Appendix attached hereto.

Since the meetings of the Sixth Pacific Science Congress much concentrated attention has been given to the oceanography of the Pacific. This resulted, to a large extent during the war, from the continuous demand of military authorities for general oceanographic knowledge, for details concerning the currents in different parts of the ocean, for the necessity of predicting sea swells and waves, for requests for information concerning the variations and the depths of the thermoclines of many areas, the distribution of temperature and salinity gradients, and the nature of the topography of the ocean bottom in many localities. There was also a demand for information as to the distribution and abundance of fish as a source of food in the several areas.

The means of presenting some of these results as well as reports of special oceanographic activities and research programmes of many laboratories will be through the excellent programme arranged by Mr. A. W. B. Powell, organizing chairman of the Division of Oceanography, and likewise the representative of New Zealand on the International Committee. This programme may therefore be considered as part of the report of the International Committee on Oceanography in its attempt to give to the Congress a comprehensive understanding of the recent advances in the oceanography of the Pacific.

Undoubtedly the chief factor that has aided in the acquisition of oceanographic knowledge has been the improvement and development of many interesting and useful instruments. Some of these instruments were devised and perfected during the war at the Woods Hole Oceanographic Institution in Massachusetts working in co-operation with agencies of the United Kingdom as well as those of the United States.

It is interesting to refer to records of earlier meetings of this Pacific Science Association. There are statements there made lamenting the lack of soundings in all parts of the Pacific beyond the continental shelves. It is stated that there was one sounding in deep water for each ten thousand square miles of ocean. The time, labour, and expense involved in securing just one sounding was considerable, and even the accuracy of the soundings available was questioned.

The *fathometer*, an instrument developed during the past several decades in the United States and Great Britain, was further perfected during the war. Sound travels through sea-water at nearly 1,500 metres per second. The fathometer operates on the principle of measuring the time-interval required for a sound emitted from the hull of a vessel to travel to the ocean bottom and there be echoed back to the vessel, where it is picked up by the hydrophone. The impulse received will be amplified electrically and recorded by a stylus moving over a roll of recording paper, the ruled graduations of the paper translating the time-interval into the depth of water under the vessel, or the impulse may be registered by a rotating disk the time-interval required recording as the depth on the rotating disk. Thus by the flick of an electric switch the fathometer is caused to function and the depth of water under the moving vessel recorded in a few seconds. Hundreds of thousands of soundings have been obtained, abysmal chasms and troughs have been charted, and many seamounts have been discovered. Several papers to be presented later will undoubtedly treat the fathometer in more detail and the corrections necessary to be applied to the observed readings for proper geological interpretation. The intensity of the impulse received by the hydrophone will also indicate to a trained observer much about the nature of the ocean bottom. The fathometer has often been used by fishermen for locating schools of fish as the sound is reflected from the backs and sides of the fish, thus indicating the exact depth at which the fish are and the distance from the sea bottom.

The *bathythermograph* is an instrument devised by Dr. A. F. Spilhaus and developed by him and his associates at the Woods Hole Oceanographic Institution. Originally it was intended to serve as an instrument for detecting the depth of mixing of the surface waters of the sea by the wind. However, the instrument as now used presents an excellent portrayal of the temperature gradient down to depths of about 150 metres and clearly indicates the depth of a thermocline when one exists. The instrument is being further developed so that records of the temperature gradients to even greater depths may be obtained.

The bathythermograph consists of a cylinder with a heavy brass nose-piece. Within the cylinder are sylphon bellows attached to a slide carrier into which a smoked-glass slide is inserted. A stylus, which moves over the slide, is connected to a bourdon tube, which in turn is attached to a coil of copper capillary tubing. The copper tubing contains xylol, and the expansion or contraction of this liquid gives a means for noting thermal changes. The sylphon bellows is a spring that will be compressed 1 in. with a tension of 320 lb. The adapter, carrying the smoked-glass slide, is firmly secured to the sylphon bellows and moves with the pressure, the indication of depth, on the long axis of the instrument. The stylus, fitted to the Bourdon tube, moves with the temperature change on the transverse axis. A change of 0·1° F. can be detected.

Each instrument must be carefully calibrated in a pressure tank at known temperatures and pressures. At present there are two institutions in the United States equipped for calibration of the bathythermograph—namely, the Woods Hole Oceanographic Institution and the Scripps Institution of Oceanography—and in Great Britain at the Teddington Laboratories. The bathythermograph has the decided advantage of being used while a vessel is underway. The observations may be made just as rapidly as the slides can be adjusted, the instrument put in place, then dropped to a given depth and hauled in again. In practice the instrument functions to a depth of about 150 metres, giving a continuous curve showing the changes of temperature with the depth. Within a few hours much detailed information on the nature of a water area can be readily and easily obtained by a number of casts with the bathythermograph, and in a far more detailed manner than by the classical methods of reversing thermometers. The exact depth of the thermocline is directly ascertained. Much more information on the bathythermograph will undoubtedly be given by Dr. John P. Tully, of Canada, in the paper he is to present.

The *salinity-temperature-depth-recorder* is a magnificent instrument likewise developed at the Woods Hole Oceanographic Institution, in co-operation with the Bristol Company, for the study of coastal waters and the waters of estuaries where there are considerable changes in the temperature and salinity gradients. During the summer of 1948 Dr. Alfred C. Redfield, of the Woods Hole Oceanographic Institution, and Dr. Clifford A. Barnes, of the Oceanographic Laboratories of the University of Washington, used the instrument with marked success in the study of waters of Washington Sound, which includes the San Juan Archipelago in the State of Washington. These waters are characterized by cold oceanic water that has been upwelled off the coast of Washington and British Columbia and is carried through the Strait of Juan de Fuca northward into Washington Sound. From the north there flows during the summer months the much warmer surface waters from the Strait of Georgia, which represent dilution by the Fraser River. The instrument has also been used by the Oceanographic Group attached to the Pacific Biological Station at Nanaimo, British Columbia, for the study of the waters of the estuaries of the west coast of Canada.

The instrument consists of a submersible "head" containing the measuring elements assembly and a deck mechanism fitted with a computing and amplifying system for "processing" and recording the measurements. The "head" can be lowered to depths of nearly 200 metres. It contains a resistance thermometer to measure the temperature, electrodes for conductivity, and a Bourdon tube element for pressure. These instruments continuously relay the measurements to the deck mechanism, which computes salinity from temperature and conductivity and translates pressure into depth. The temperature and the mechanically computed readings of salinity and depth are recorded simultaneously in lines of different coloured inks on a synchronized paper-strip chart. Temperature with the present instruments available can be measured over a range from —2·0° c. to 32° c. with an error not exceeding 0·1° c.; salinity throughout a range of $20^{\circ}/_{00}$ to $40^{\circ}/_{00}$ with an error not exceeding $0{\cdot}3^{\circ}/_{00}$. The maximum depth error is approximately 2 metres over the range of 185 metres.

Vertical profiles of water structure can be taken by lowering the sensitive head of the instrument from a drifting vessel. By towing the head of the instrument just below the surface a horizontal view of the water structure can be obtained along a ship's course. The quick response and the continuous recording features of the S-T-D adapt it particularly to obtaining the overall pattern of water structure and thermal changes in coastal waters.

Coring Devices: Mention should also be here made of the several forms of apparatus used in securing long cores from the floor of the ocean depths and which are bound to play an important role in geological exploration. The first successful device for securing long cores showing the structure of the ocean floors was developed by Dr. Charles S. Piggott, formerly of the Geophysical Laboratory of Washington, D.C. Very recently Dr. Kullenberg, following suggestions of Dr. Hans Pettersson, the Swedish oceanographer, has materially improved the core sampler. With the Piggot sampler cores of 6 ft. to 12 ft. were obtainable, while it is understood that cores up to 50 ft. in length may be secured with the Kullenberg apparatus. It is obvious that these core samplers are a tremendous advance for collecting samples of the ocean bottom over that of putting a chunk of lard on the end of a sounding lead or by the use of a grab sampler.

The *underwater camera* is another remarkable piece of apparatus that has been recently employed and is being further developed by Dr. Maurice Ewing, of Columbia University, working through the Woods Hole Oceanographic Institution. Pictures of the ocean floor and the life thereon have been readily obtained to depths of approximately 200 metres, and last year Ewing was successful in getting pictures to far greater depths.

A *current meter* developed by Commander Roberts, of the United States Coast and Geodetic Survey, is a convenient device for recording coastal currents by remote control over a considerable period of time. The instruments are attached to secured buoys placed in the area where the desired measurements are to be made. At given intervals, depending upon the velocities of the current, the rotator of the current meter makes a contact which produces a radio wave. This radio wave can be picked up at a shore station and recorded mechanically some miles from the anchored buoys.

Improvements continue to be made in various types of gear used for collecting biological material, and especially for making quantitative measurements. Here, however, the conditions are vastly more complicated, and no advances as revolutionary as the instruments of physical oceanography have been experienced.

Information concerning the tides of the Pacific area has been materially increased, and the advances that have been made will be given in a paper by Mr. E. C. McKay, of the United States Coast and Geodetic Survey.

The nature and the prediction of sea swell and waves has received much attention both from the theoretical and practical standpoint from many oceanographers, particularly those of the United Kingdom and the United States. Much more will be heard on this very important subject through papers that will be presented to this congress.

The sea offers much to challenge the chemist and the chemical engineer for producing many types of materials to resist the corrosive and solvent action of sea-water and upon which the organisms living in the sea will not prey and destroy. Many studies on the chemistry of sea-water have been made, especially on the occurrence and distribution of some of the elements occurring in small quantities. Interest is being manifested currently in the existence of the isotopes of the various elements in sea-water and marine organisms. Papers to be presented to future congresses of the Pacific Science Association will undoubtedly contain much on the distribution of isotopes and also upon the utilization of radio-active tracers applied particularly to the study of marine organisms.

The recovery of common salt, sodium chloride, from sea-water is one of the oldest of industries. This compound, so necessary to life, is also one of the basic raw materials of modern commerce, for it or the elements or compounds derived from it are necessary for the manufacture of hundreds of other substances and materials. Hundreds of thousands of tons of sodium chloride continue to be taken from the sea each year. The technological advances of recent years has caused the erection of enormous plants for the recovery of various compounds of magnesium and bromine from sea-water. In several localities, using very efficient evaporators, water itself is being distilled from the sea and sodium chloride, together with compounds of magnesium, potassium, and bromine, recovered from the brines.

With the ever-increasing population of the world the problem of sufficient food supplies is becoming acute in many quarters of the world. Since the cessation of hostilities considerable impetus has been given to the exploration of the sea, particularly of the Pacific, as a source of future food by groups within the United Nations Organization. By treaty between several nations various international commissions have come into being to study fishery resources and to write regulations ensuring intelligent use of these resources.

The importance of vitamins to the well-being of man is now universally known. Products of the sea, particularly fish-livers, have supplied great quantities of these spark plugs of nutrition. I well recall some years ago when my colleague Dr. W. F. Thompson, then in charge of the International Halibut Commission, urged the halibut fishermen to preserve the fish livers for sale to pharmaceutical houses. At first the suggestion was considered rather idiotic by the fishermen. To-day, however, the money derived from the sale of halibut livers more than pays the full cost of operation of a fishing-vessel. By-products of the fishing industry are being extensively used as the source of fish-oils, cattle food, and fertilizers.

Thus with increasing knowledge of the sea and its products, coupled with advances in technological processes, man is learning to use more effectively the material available to him in the sea. However, in no manner has he attempted to exploit the sea as he has the land. Scientific farming of the land has given rise to greater productivity ; animals have been bred to give greater quantities of milk, or of meat, or of wool. Many and better plants, unknown to our grandfathers, have been created. All of this has come about by an orderly process of research and education, fostered by basic research in the fundamental sciences. Attempts to make the sea more productive, to produce better and more useful marine plants, fishes, and mammals have scarcely been made.

Large areas of land were unproductive because of lack of water, but by building dams and bringing water the deserts, rich in nutrient materials were made to bloom and produce. There are vast expanses of ocean unproductive because of lack of nutrient salts, yet from oceanographic studies it is known that a few metres below the thermocline of these barren areas and out of contact with the life-giving energy of the sun are unlimited supplies of nutrient salts. Perhaps some day means may be devised whereby these rich waters will be brought nearer to the surface to promote growths of phytoplankton upon which the fishes and mammals of the sea may graze.

The potential energy of the rivers of land areas has been converted to useful electrical energy, but the enormous potential energy available within the sea yet remains to be utilized.

Exploration of the continental shelves, using geophysical instruments, is being conducted in many quarters in the search for oil and minerals.

The chairman of this committee desires at this time to present the following recommendations for consideration by the Seventh Pacific Science Congress :—

It is recommended that—

1. The several countries adhering to the Pacific Science Association, in which there are extensive facilities for oceanographic research, be requested to form a National Committee on the Oceanography of the Pacific, providing that such a committee does not already exist.
2. Each National Committee on the Oceanography of the Pacific shall name one of its members to serve also as a member of the International Committee on the Oceanography of the Pacific of the Pacific Science Association.
3. The several countries adhering to the Pacific Science Association in which a national committee on oceanography does not exist be requested to appoint a scientist for service on the International Committee on the Oceanography of the Pacific.
4. The Pacific Science Association shall name the chairman of the International Committee on the Oceanography of the Pacific.
5. The International Committee on the Oceanography of the Pacific shall be empowered to function during the interim between congresses in order to facilitate oceanographic investigations in all countries bordering on the Pacific, to aid in the exchange of oceanographic information, and to assist students and investigators desirous of pursuing their studies and investigations beyond their national borders.
6. The Pacific Science Association request that the International Committee on the Oceanography of the Pacific be represented on the International Committee of Oceanography set up by the Combined Unions of Biological Sciences and of Geodesy and Geophysics.
7. The Pacific Science Association request that the International Committee on the Oceanography of the Pacific be represented on any commissions dealing with oceanography within the United Nations Organization.

OCEANOGRAPHIC STUDIES MADE BY ARGENTINA

By Pedro S. Casal, Sociedad Argentina de Estudios Geograficos

These studies are of great importance to us because the continental shelf which borders our coast is very extensive ; there is a warm current which comes from the north and meets other cold ones (from the " Malvinas " and the Antarctic) and, besides, the tides of the Pacific and of the Atlantic mutually influence each other in the southern part, producing physical and biological phenomena which it is necessary to determine with precision.

The large Antarctic icebergs sometimes invade the continental shelf for reasons which are as yet unknown. At first we oriented our studies to the hydrographic mapping of the coast. This has required many years of work because the coast is approximately 5,000 kilometres long and is open to the Atlantic. This necessitates an earnest study of the tides whose amplitude is of great importance to the life in the ports. Although at the mouth of the Plata River the amplitude of the hightide is only 1 metre, more or less, in some ports on the coast the amplitude is from 12 to 14 metres. In these ports the boats cast anchor at high tide near the coast in order to stay high and dry when the cargo is taken off. In this manner the hulls can be cleaned during the time the ships carry out their operations of loading and unloading by means of horse-wagons, or some other means. We are dealing here with ports or bays in Patagonia, with low density of population, where it is convenient when possible to avoid the use of motor-boats for the transferring of merchandise, animals, &c.

We have already installed some important geodetical tide gauges and we plan to have six distributed in the most convenient coastal ports. The tide-gauge net will be completed with other apparatus of the "patron" type of which twenty instruments will be installed and twelve or more of the portable type will also be installed. Many of these instruments have been in operation for some time, and what is lacking is going to be integrated. This material has been acquired from the United States. The immediate needs of our country in oceanography lie within the Great Continental Platform, and therefore our greatest oceanographic efforts are concentrated here.

Thermometers—We utilize reversing thermometers, &c., of the classic type. The same can be said with regard to the dredging and the apparatus used to collect specimens from the bottom in such a way as to preserve their stratification. The dredging which has given us the best results is on the smooth ocean floor, although in certain places the results have been satisfactory on the rough ocean floor.

The extractions from the ocean floor have not in general given us good results as specimens of stratification, and a new type is being studied at present. In order to obtain certain organisms which live in the sand or mud, some years ago we designed an apparatus which gave us good results and is easy to set up in the same oceanographic vessel. It is used by towing it slowly.

Soundings.—We utilize the acoustic ones and also the sounding-lines in dealing with stations where we wish to determine the oceanographic elements at different depths.

Current Meters.—We utilize those of simple construction which can be made on board, or the modern type "Gurley," Eckman, Idrac, which give us the intensity of the currents at different depths with the corresponding photographic record.

Physical-chemical Elements of the Sea-water.—These are determined in the laboratories on land ; the oceanographic vessel only collects the samples.

Biological Stations.—In the case of our oceanographic vessel, "Patria," we have a rudimentary laboratory in the open air and another below deck. but the most important part of the work is done in the laboratories on land with data brought from the ship. On our continental shelf we do not have nearby ports for work of this type, except in certain sectors. The same situation exists south of the Strait of Magellan to the Argentinian Antarctic sector.

Plankton.—The collection of this important element, which gives us an indication of the biological wealth of certain zones, is made with known methods and nets, but its detailed study is made on land.

The Government of Argentina is stimulating oceanography, the study of which lies in the hands of the Navy. At the present various Argentinian officials are studying oceanography in the United States in order to acquire the methods and experience of that country.

COMMONWEALTH OF AUSTRALIA: OCEANOGRAPHY OF THE PACIFIC

By H. Thompson, Chief of Division of Fisheries, Marine Biological Laboratory, Cronulla, New South Wales

In Australia most of the oceanographical research since 1939 has been done by the Division of Fisheries, Council for Scientific and Industrial Research, though some small biological problems have received attention in the Departments of Zoology in the Universities of Sydney, Adelaide, Tasmania, and Western Australia. The Hydrographic Branch of the Department of the Navy undertook survey work, particularly in the northern Australian area, during the war. The Bureau of Meteorology, working in conjunction with the Royal Australian Air Force, produced considerable material on weather conditions in the whole area.

Much of the oceanographical work of the Division of Fisheries of C.S.I.R. between 1939 and 1942 was done by M.V. "Warreen," the research vessel of the Division. She worked particularly in the waters of south-east Australia, where extensive hydrological and planktological programmes were carried out. The results of the hydrological work are in manuscript form, but portion of the material is to be presented to the A.N.Z.A.A.S. meetings in Hobart in January, 1949.

After 1942 the programme was greatly curtailed because M.V. "Warreen" went on active service, and only a small staff was left to do this work from land-based stations. Since the war the exploratory work of the Division has been increased, and with four research vessels operating the oceanographical programme will be greatly extended. The following vessels will be working during the remainder of the current year (1948–1949, June):—

1. F.R.V. "Warreen," working in *Western Australia,* particularly on exploratory fishing tests, but also undertaking oceanographical research.
2. F.R.V. "Liawenee," working in *Tasmanian Waters* on the biology of barracouta, shark, and crayfish, with a hydrological programme to support the biological studies.
3. M.V. "H. C. Dannevig," working for six months off the *New South Wales* coast, undertaking biological research on the trawl fishery of New South Wales and carrying out a hydrological programme at several stations on the coast from Coff's Harbour to Eden.
4. F.R.V. "Stanley Fowler," undertaking pearl-shell investigations in the Thursday Island (*Torres Strait*) area, when a biological survey will be made, and methods of cultivation studied.

All of these vessels will work primarily on fisheries biological programmes, but in each case hydrological observations will be made and plankton hauls taken at regular stations.

Our oceanographical research in the whole area will concentrate on four main problems:—

1. *The Assessment of the Productivity Cycle in Australian Coastal Waters.*—This will be done by long-term collection at frequent intervals, preferably monthly, of physico-chemical and biological data at stations

adjacent to laboratories equipped to do the necessary analytical work. The physical investigations will be concentrated on circulation, mixing, and light-penetration studies. The chemical investigations will be concentrated on the level of abundance, production, and degeneration cycle of a number of key nutrients, such studies to be linked with similar investigations into the chemistry of bottom deposits and of the adjoining estuarine and fluviatile waters. The biological investigations will be devoted to a study of the annual and seasonal level of abundance and of the growth cycles of a number of key organisms and plankton groups.

Up to the present, investigations on this problem have been carried out in the *South-east Sector*, so that the collection of the chemico-physical data, with the exception of submarine light penetration, has been done over a period of five years in the case of the initial station off the site of the Laboratory at Port Hacking, and for a shorter period at a number of later established stations.

The data from oceanographical investigations have been supplemented by an extensive estuarine programme which has been carried out for approximately five years. Steps are now being taken to collect the light penetration data and to begin a chemical analysis of bottom deposits in this sector.

In the *South-west Sector* a similar level of investigation has been reached, although, owing to the nature of the shelf, the sampling stations have been extended into section lines at each point of the investigation, and an estuarine programme has been carried out at the same time.

In both sectors plankton sampling has been confined mainly to surface, with occasional oblique and vertical hauls, using standard N70 " Discovery " nets. A considerable extension in the study of diatoms and bottom flora and fauna will be necessary to supplement the biological information now available for these areas.

2. *The Study of the Circulation Trends in Australian Waters.*—In the *South-east Sector* data were collected by F.R.V. " Warreen " prior to 1942, although the working of section lines was not commenced until August, 1940. Owing to wartime exigencies these section lines could not be worked sufficiently wide to enable sampling in the core and beyond the east Australian current system. For these reasons, although the broad details of onshore circulations are known in this sector, considerable supplementary work is necessary to supply this missing information.

In the *South-west Sector*, F.R.V. " Warreen " has commenced a deep-sea programme of oceanographical research, working 100-mile section lines as frequently as possible in selected areas.

3. *The investigation of the productivity aspects of upwelling in the North-west sector.*—The only oceanographic data available for this area have been collected by Japanese pearlers, and these indicate that the centre of occurrence of the upwelling occurs about lat. 20° S. in the spring period, and is distributed over about 150 to 200 miles on the continental shelf.

A certain amount of preliminary data will be collected by " Warreen," but a deep-sea vessel capable of independent working would need to be based on Broome or Darwin to work section lines at regular and frequent intervals, to give data on the physical processes of upwelling.

4. *The Study of the Oceanography of Australian Waters in General.*—At present very little data are available for the Australian section of the area to the north of the Continent. Work could be most easily carried out from a deep-sea vessel based at Darwin and working between North-west Cape in Western Australia and Brisbane in Queensland. This work should preferably be integrated into an overall programme for the Timor, Arafura, Java and Banda Seas by international agreement. A fully-equipped vessel, containing both biological and chemical laboratories, would be needed to do the work.

GREAT BRITAIN

By G. E. R. Deacon, Admiralty Research Laboratory, Teddington, Middlesex

N. A. Mackintosh and H. F. P. Herdman published a paper, " Distribution of the Pack-ice in the Southern Ocean," Discovery Reports, Vol. 19, pp. 285–296, Cambridge, 1940, in which they give the mean position of the northern edge of the ice based on all the observations made by the Discovery Committee's ships, whale-factories, and other expeditions. They discuss the advance and retreat of the northern boundary of the pack-ice, and give a rough idea of the latitude in which the ice-edge is likely to be found in any particular month.

N. A. Mackintosh has published " The Antarctic Convergence and the Distribution of Surface Temperatures in Antarctic Waters," Discovery Reports, Vol. 23, pp. 177–212, Cambridge, 1946. He tabulates all the crossings of the Antarctic convergence by the Discovery Committee's ships and uses all the continuous thermograph records to construct charts of the surface isotherms in the Southern Ocean for each month. They give a more realistic picture of the temperature distribution than could be obtained by averaging the surface temperature observations made in each 1° or 5° square, and show how the isotherms crowd together near the Antarctic convergence. It is found that the great majority of the crossings of the convergence fall within 75 miles of the mean position.

H. F. P. Herdman has published " Soundings Taken During the Discovery Investigations, 1932–39," Discovery Reports, Vol. 25, pp. 39–106, Cambridge, 1948. He gives a new bottom chart of the Ross Sea, questions the existence of a submarine connection between New Zealand and Macquarie Island, and gives new information about the bottom topography near the Balleny Islands. He gives a brief summary of a large number of profiles obtained in the neighbourhood of the South Shetland Islands. It is noted that the echoes are always weak in the neighbourhood of the Antarctic convergence ; two possible causes are mentioned : the mixing of the water masses in the boundary region, and the presence of a very soft deposit of diatom ooze.

G. E. R. Deacon, in a paper on " Water Circulation and Surface Boundaries in the Oceans," *Quarterly J. R. Met. Soc.*, Vol. 71, pp. 11–25, 1945, has emphasized the importance of the Antarctic convergence as a biogeographical boundary and has shown how the stratification of the bottom oozes in the boundary regions between red clay, globigerina ooze, diatom ooze, and glacial sediments can be used to obtain information about the interrelated decrease in the flow of the Antarctic surface and bottom currents since the Glacial Period.

THE INTERNATIONAL COMMITTEE ON OCEANOGRAPHY, SET UP BY THE COMBINED UNIONS OF BIOLOGICAL SCIENCES AND OF GEODESY AND GEOPHYSICS

By Lieut.-Colonel R. B. Seymour Sewell, Secretary, the Zoological Laboratory, Cambridge, England

Excerpts Taken From the Minutes of the Meeting Held in the Rooms of the Royal Society of London, Burlington House, London, on 22nd and 23rd May, 1947

Members—

Appointed by the Unions—

- Dr. C. von Bonde, Department of Commerce and Industry, Central Street 216, Pretoria, South Africa.
- Dr. Charles Fish, Professor of Zoology, Rhode Island State College, Kingston, R.I., U.S.A.
- Professor B. Helland Hansen, Det. Geophysisk Institut, Bergen, Norway.
- Dr. Harald U. Sverdrup, Director, Scripps Institute of Oceanography, La Jolla, U.S.A.
- Professor Hans Pettersson, Oceanografiske Institutet Stejbergstorget S., Goteborg, Sweden.
- Professor J. Proudman, F.R.S., The University, Liverpool, England.
- Professor Dr. H. Boschma (Convener), Rijksmuseum van Natuurlijke Historie, Leiden, Holland.

Co-opted Members—

- Lieut.-Colonel R. B. Seymour Sewell, C.I.E., F.R.S., The Zoological Laboratory, Cambridge, England.
- Professor Louis Fage, Institut Oceanographique, 193, Rue Saint-Jacques, Paris, Ve.
- Professor W. J. Dakin, Department of Zoology, University of Sydney, Sydney, Australia.
- Dr. E. C. Bullard, F.R.S., Department of Geodesy and Geophysics, Cambridge.

Members Present—

- Dr. H. Boschma (Convener).
- Professor Hans Pettersson, of Sweden.
- Professor Proudman, of Liverpool.
- Dr. R. B. Seymour Sewell, of Cambridge.

The meeting was also attended by Professor F. J. M. Stratton, F.R.S., General Secretary of the Conseil International des Unions Scientifiques.

Dr. H. Boschma was elected as Chairman of the Committee and Dr. R. B. Seymour Sewell was appointed Secretary.

It was decided to consider the co-optation of additional members to the Committee—

- Dr. Ph. H. Kuenen, of Holland.
- Dr. Bullard, F.R.S., of Cambridge.
- Dr. Louis Fage, of the Musee d'Historie Naturelle, Paris.

It was proposed that Dr. Dakin, of Sydney, Australia, should be co-opted. This was agreed to.

The Committee considered proposals put forward by Professor Hans Pettersson, which were as follows :—

It is proposed that future investigations of the deep ocean bed by means of new technique, developed during the war years, shall be organized on an international scale in order to prevent overlapping of individual efforts and in order to concentrate the work on problems of outstanding importance.

As problems of this nature, falling within the realm of geophysics, the following may be mentioned :—

A. Deep coring in the deeper basins of the oceans and also across and near ridges like the Central Atlantic Ridge ; also along lines converging towards active or recently extinct volcanoes, and towards atolls and areas where recent elevation or subsistence of the ocean-bed is suspected ; also along the continental slope of regions like the " De Geer " line and near broken off mountain chains. Special attention should be given to coring along border lines between different kinds of sediments.

B. Measurements of the thickness of the sediment by means of echo-sounding in the above localities, and also where former land connections are suspected. Especially needed are comparisons of the thickness of the sediment in the Atlantic Ocean as compared with the Pacific Ocean, which may supply evidence for or against Continental drifting.

C. Measurements of the geothermal gradient in the basins and the deeps, especially where the rate of sedimentation may be expected to show very low values.

D. Suggestions for the biological programme in deep-sea research—

(1) Design of experimental apparatus (grabs, &c.) for the investigation of the bottom fauna.
(2) The study of the invertebrate fauna in great depths.
(3) The microfauna of the detritus layer.
(4) Metabolism in animals living at temperatures below zero.
(5) Quantative study of animal associations on the oceanic slopes.
(6) The fauna of the abyssal plains and deeps.
(7) Pelagic micro-organisms.
(8) Ecology of the foraminifera.
(9) The nutrition of deep-sea organisms.

It is recommended that work on similar lines to the above should be undertaken by any oceanographic institute that may be founded in the future.

The Committee considered a proposal put forward by Dr. R. B. Seymour Sewell for the foundation of an Institute of Oceanography for the study of the Indian Ocean, which was as follows :—

In the report of the Preparatory Commission (Natural Sciences Committee) of UNESCO (*vide* Science and UNESCO : International Scientific Co-operation, page 33) it is recognized that " Those carrying out work for the International Council for the Exploration of the Sea should be associated with UNESCO as well as with FAO," and they further recognized that Asiatic waters have never been covered. It was to remedy this great gap in our knowledge that at the meeting of the Committee on Oceanography and Fisheries of the British Commonwealth Scientific Conference, held at the Royal Society's Rooms in June–July, 1946, I suggested the formation of an Institute of Oceanography for the Indian Ocean, and the Committee passed the following resolution :—

" The Specialist Committee urges on the Governments of the countries bordering the Indian Ocean the desirability of close co-operation in studying the oceanography of that ocean. It suggests that such co-operation might be greatly facilitated by the establishment of an Institute of Oceanography in a suitable location, under the joint control and support of the Governments concerned."

(Unfortunately at the present moment certain of those Governments are in a state of flux, notably India and the Dutch East Indies.)

By the recommendations of the Sub-Commission on Natural Sciences of the General Conference (1946) of UNESCO, the Secretariat is instructed (in para. 10, (*h*)) " to explore the possibility of the foundation of new international laboratories," one of which is specifically mentioned—namely, (*h*) Oceanography and Fisheries of the Indian Ocean.

There is an enormous area of the Indian Ocean, especially the region to the south of the Equator to about lat. 40° S., of which we know practically nothing; and the investigation of this region is highly desirable from the point of view of pure scientific research; but perhaps the greatest claim for the support of such a project comes from the very intimate relationship that exists between oceanography and fisheries. In the publication "Science and UNESCO: International Co-operation" (page 54) it is noted that of the four basic needs for the non-industrial countries, such as India, which the Economic and Social Council will be taking into consideration, the first is "Increased production of food per man-power per day," and this is one of the prime concerns of FAO.

Around the Indian Ocean a number of Governments have realized that in the present state of the world's and of local food supplies it is essential that the fisheries should be improved and the methods of fishing be brought up to date and modernized. In order to ensure that this increased exploitation of the fisheries will not be carried on in an unscientific and harmful manner India has recently adopted a scheme for the establishment of a Central Fishery Research Institute with Fishery Research Laboratories on each coast, east and west.

In addition to India, South Africa, the Islands of the Indian Ocean (Mauritius and Seychelles), Ceylon, and Malaya all have their Director of Fisheries and are carrying out research into their own local problems. In each of these areas a certain amount of pure oceanographic, as well as fishery, observations will of necessity be made, but in order to co-ordinate and correlate the work of these isolated fishery researches it is essential that there should be an Oceanographic Research Institute that would carry out researches in those areas that lie beyond the range of the local fishery research vessels.

In this way we should be doing something to co-ordinate scientific knowledge and economic development.

The committee considered proposals submitted by Dr. C. von Bonde, of South Africa, which were as follows:—

It is difficult to formulate plans for discussion at the proposed meeting, but the following matters appear to be of importance to our work in South African waters:—

(*a*) Practical work at sea is being held up at the present moment owing to the severe shortage of oceanographic instruments, deep-sea thermometers, and glassware for chemical analyses of sea-water. It is suggested that the International Council for the Exploration of the Sea in Copenhagen be requested to arrange for the immediate manufacture and means of distribution of such apparatus.

(*b*) Methods of chemical analyses of sea-water should be standardized and printed in English, French, and German, and such publications should be available to marine laboratories throughout the world.

(*c*) Anything that can be done to standardize oceanographic routine practice at sea would be an advantage.

(*d*) Co-operative work between different marine laboratories as a means of collecting simultaneous observations at sea on specific problems throughout the oceans of the world should be encouraged, but particular emphasis should be made in regard to problems affecting immediate increases of fish products, having regard to the world shortage of food proteins and fats.

I wish to suggest that a member of the International Council for the Exploration of the Sea, Copenhagen, Denmark, be also co-opted.

Dr. Boschma submitted a series of proposals that had been sent to him by Dr. Kuenen. Dr. Kuenen's proposals were as follows:—

1. Sedimentation in shallow seas, especially inland seas and shelf areas. These form the closest analogy to fossil sedimentation basins, in which most ancient sedimentary rocks were deposited. So far more attention has been given to deep-water deposits, but from the geologist's point of view the systematic investigation of an inland sea is of at least equal interest: nature and distribution of the sediments, wave and current action, organic content, &c.

2. The morphology of the Atlantic continental slope of Europe especially to ascertain faults, submarine canyons, &c.(¹).

3. Dredging to carry forward the investigations of Bougart's tracts of submerged beach conglomerates at depths of 50 to 400 metres on the continental slope.

4. If Pettersson's programme is carried out, his results will be of outstanding importance in formulating a programme for further work(²).

5. Geophysical investigation of the continental slope and deep-sea floor.

6. Under-water photography as developed in the U.S.A. during the war. If the technique could be applied to greater depths, that would be of outstanding importance.

7. Current and silt measurements close to the bottom under varying circumstances, especially during rough weather and along breaks in slope. This would teach us more of the transport of sediment and the existence of new-depositional environments.

8. Chemistry of sea-water, especially the problem of solution and precipitation of lime (bottom water, surface layer).

9. Chemical analyses of sediments, both of bulk samples and individual samples, for geochemical investigations.

10. Radioactive age determination of log samples.

11. The influence of organisms on the deposition of fine particles.

12. The compilation of a new world chart.

Addenda

(1) Sounding of the European continental slope will require the co-operation of hydrographic surveys. An outstanding problem is to carry the investigation of a few submarine canyons right out to the deep-sea floor to ascertain whether they end in a " delta " or otherwise. Position finding by radar might solve the problem of locating the position of soundings.

(2) Many thousands of samples will have to be taken from the cores and examined regarding mineralogical, radio-active, chemical and physical properties.

Professor Hans Pettersson urged the very great importance of international co-operation, especially in deep oceanic work ; he emphasized that the determination of the age of cores by means of radio-active measurement can only be done in deep-sea sediments.

Professor Proudman called the attention of the Committee to the oceanographic investigations that could be undertaken by the meteorological observation vessels and the necessity for the co-operation of the International Association (of Physical Oceanographers) and their collaboration with the International Committee on Oceanography. Such vessels would provide opportunities for continuous observations in more or less fixed positions. The British vessels would probably be able to carry out observations on the surface water, and possibly each country concerned in the scheme would organize certain researches for its own vessels.

The Committee discussed the possibility of the re-establishment of the Oceanographic Institute at Monaco as an operating Oceanographical Laboratory.

Dr. Boschma submitted to the Committee a report by Dr. Margaretha Brongersma-Sanders, of Leiden, Holland, on the occurrence and causation of mortality in fish on the coast of South-west Africa (particularly Walvis Bay) associated with the presence of " red water," and urging the desirability of carrying out research into certain phenomena in this region. A precis of the report follows :—

In some of the bays on the coast of South-west Africa (especially Walvis Bay) and sometimes in the neighbouring open sea there is a periodic mass-mortality of fish, which always occurs in the southern summer (December). In the same area there is a peculiar bottom sediment, characterized by a high organic content, great quantities of H_2S. gas and a nearly complete absence of living organisms, other than anærobic bacteria ; in this deposit are numerous fish remains and a very high percentage of the skeletons of diatoms. This azoic area extends from Cape Cross to south of Conception Bay (lat. 21° 20′–24° 30′ S.) and from near the coastline out to about the 77 fathom line, a width of about 25–30 miles. The azoic area is separated from the shore by a coastal belt in which the bottom is fine grey sand and there is an absence of H_2S.

The active cause of the mortality is by many attributed to the H_2S gas, but the origin of this gas is in dispute. It may be either (1) carried down as sulphur compounds from the land by rivers, or (2) due to the reduction of sulphates in the sediment by anærobic bacteria.

Dr. Brongersma-Sanders puts forward a third suggestion—namely, that the mortality is attributed to the presence of "red-water," caused by the presence of large numbers of Dinoflagellates, associated with up-welling water. Similar phenomena of up-welling water, large numbers of Dinoflagellates, and fish-mortality occur in other regions (*e.g.*, California, Peru-Chile, and perhaps the South coast of Arabia), and a similar area seems to have existed in past geological times in the northern Caucasus. The Walvis Bay azoic sediment shows a remarkable resemblance to certain bituminous fish-shales.

The action of the Dinoflagellates may be attributed to either (1) the production of a toxin or (2) asphyxiation by the mechanical clogging of the gills.

In California there seems to be a close connection between the total number of Dinoflagellates and a toxicity of the mussels, the shell-fish themselves being resistant to large quantities of the poison that is probably produced by the Dinoflagellates.

The following studies should be carried out :—

A. A quantitative and qualitative study of the plankton throughout the year What oceanographic peculiarities are associated with the occurrence of "red-water"? What is the extent of the "red-water" in different years, and does it coincide with the azoic area ?

B. A study of the bottom sediment to determine its nature (Guttja or Sapropelium) ; the nature of the enclosed organic compounds ; the presence of certain metals, such as Cu, Ni, Va, Mo, &c. Determination of the organic carbon and nitrogen from the top layer and at deeper levels of the sediment. Does the O_2/H_2S boundary lie at the surface or at some distance below ?

C. Is the fish mortality due to a toxin, related to the paralytic shell-fish toxin, that is produced by the living Dinoflagellates, and does paralytic poisoning of man from eating mussels during the summer occur on the South-west African coast ?

Professor Hans Pettersson suggested that UNESCO should be approached and be asked whether it would consider the appointment of an Assistant Secretary, who, working under the Secretary, would keep in touch with "liaison" representatives in all countries that are interested in oceanographic work and so keep the Committee informed regarding any oceanographical investigations that were being carried on or were contemplated in both the physico-chemical and biological branches.

The following resolutions were passed :—

1. The International Committee on Oceanography have heard with very great interest Dr. Hans Pettersson's account of the Swedish plan to study the deep ocean bed and its fauna, and of the possibility of a further extension and continuation of this work through co-operation between the Scandinavian Countries—Sweden, Norway, and Denmark. The Committee considers that such investigations are of the greatest value from the scientific point of view ; and that they would benefit from international co-operation and should be organized on an international scale.

2. The International Committee on Oceanography noted with great interest the proposal (contained in para. 10 (*h*), of the Digest of Directives, Sub-Commission on Natural Sciences, UNESCO General Conference, 1946) to explore the possibility of founding an Oceanographical and Fisheries Laboratory for the Indian Ocean. The Committee consider that the creation of an Institute of Oceanography for the Indian Ocean would be of the greatest value for the advancement of our scientific knowledge of this region. They also consider that such an Institute would probably lead to considerable economic advantages for all countries bordering on this ocean, and earnestly trust that means will be found for the establishment of such an institution.

The Committee also hope that, if and when the constitution of such an institution is being considered, full advantage will be taken of the experience gained by the International Council for the Exploration of the Sea.

EXCERPTS TAKEN FROM THE MINUTES OF THE MEETING HELD IN OSLO, NORWAY, 19 AUGUST, 1948

Members present—

Professor H. Boschma (Chairman).
Professor Louis Fage.
Professor J. Proudman.
Dr. Harald U. Sverdrup.
Lieut.-Colonel R. B. Seymour Sewell (Secretary).

Visitors who attended the meeting—

Dr. J. N. Carruthers.
Mr. Jens Smed.
Dr. Johan T. Ruud.
Lieut.-Commander J. R. Lumby.
Dr. F. S. Russell.
Dr. N. A. Mackintosh.
Dr. H. Blegvad.
Captain C. D. Meaney.
Dr. Helge Thomsen.
Dr. G. E. R. Deacon.
Dr. J. D. H. Wiseman.
Mr. John B. Hart.

CONSIDERATION OF MATTERS ARISING OUT OF THE MINUTES OF PREVIOUS MEETING

The Present Position of the Oceanographic Institute of Paris and its Oceanographic Laboratory at Monaco.—Professor Louis Fage explained the present position of the Institute. He pointed out that at the present time it is very difficult for physical oceanographers to find suitable laboratories in which to carry on their studies; there are much better facilities available to marine biologists. Professor Fage pointed out that there was before the Commission a proposal to set up an international committee of experts in order to encourage the foundation of many more oceanographic stations all over the world, but he thought that existing stations should have a prior claim to help. He had discussed the present position of the Oceanographic Institute of Paris with Dr. Joseph Needham, the representative of UNESCO at the meeting of the International Union of Biological Sciences, and it was agreed that UNESCO ought to help.

He therefore proposed that the Commission should transmit his report to the Conseil International des Unions Scientifiques and should recommend that UNESCO should be asked to give support financially to the Oceanographic Institute at Monaco.

This proposal was discussed, and it was unanimously agreed to support Professor Louis Fage's proposal. It was decided that a letter should be sent to the Secretary of the International Association of Physical Oceanography to inquire whether that Association will support such a resolution, and if they agree to do so, that the resolution should be sent to UNESCO through the Conseil International des Unions Scientifiques.

The Action to be Taken Regarding the Appointment by the International Council for the Exploration of the Sea of a Representative on the Commission.—It was proposed and carried that the Secretary should be instructed to write to the International Council for the Exploration of the Sea and ask them to appoint a representative.

Consideration of a Note, Drawn Up and Circulated to All Members of the Commission, on the Need for Establishing Marine Biological and Oceanographic Laboratories in Various Parts of the World.—The Secretary drew attention to the fact that FAO have formulated a comprehensive scheme by which the oceans and seas are divided into seven regions, in each of which it is proposed to establish an International Council on the lines of the International Council for the Exploration of the Sea, and that steps had already been taken to set up such a council for South-east Asia. The Secretary also informed the Commission that a proposal for the establishment of a marine biological and oceanographic laboratory in the Kei Islands had been brought before the International Union of Biological Sciences at their meeting in 1947, and that a Committee, of which he was Chairman, had been appointed by the Union to consider this project. This Committee had reported that, owing to lack of necessary facilities, it was considered impracticable to set up a *permanent* laboratory in these islands, but that if a parent laboratory could be established somewhere in the South-east Asian area it might be possible to have a subsidiary temporary laboratory in the Kei Islands.

Professor H. Boschma informed the Commission of the very great opportunities that exist in the area round the Kei Islands for the study of the deep-sea fauna, which here thrives in as shallow a depth as 200–400 metres.

Professor Louis Fage urged that a resolution should be sent to UNESCO, as suggested in the Secretary's note, urging the establishment of a marine biological and oceanographic laboratory in this area. He pointed out that the Food and Agricultural Organization at the meeting of international representatives that had been convened in the Philippine Islands in February last had delegated the research in a number of different branches of study to different Scientists or Scientific Institutions located in widely separate localities, as, for example :—

Hydrology to the Marine Laboratory at Batavia.

Taxonomy and Systematics of Fish to Dr. S. L. Hora, the Director of the Zoological Survey of India, at Benares, India.

Fish Migration to Dr. Herklots in Hong Kong.

Fishery Technique was to be studied in the Philippine Islands.

Such an arrangement he considered to be quite impracticable.

Dr. Carruthers (Visitor) pointed out that one could only study the migrations of fish if one was in the same area as that in which the fish were present.

Professor Louis Fage submitted the following resolution to the Commission :—

> " That this Commission request UNESCO to approach the Food and Agriculture Organization and get an international conference summoned to discuss the necessity of establishing a marine biological and oceanographic station in each of the areas into which FAO proposes to subdivide the oceans, if no such laboratory already exists ; and that representatives of those organizations that are interested in this branch of research, such as the Australian Council of Industrial and Scientific Research, the International Council for the Exploration of the Sea, &c., as well as representatives of the various laboratories in the different areas, should be invited to attend."

This resolution was carried unanimously.

Consideration of a proposal submitted by Professor Romanovsky for the establishment of a " Review of Oceanography " :—

Professor Louis Fage pointed out that a very similar proposal was being brought before the present meeting of the Association d'Oceanographie Physique by Dr. P. Green. By this proposal it was hoped that the Association d'Oceanographie Physique would resolve to establish an inclusive, periodical bibliography on physical oceanography and its border fields, preferably in co-ordination and combination with a bibliography on marine biology. Such a publication would cover most of the ground suggested by Professor Romanovsky, the main exception being the absence of special articles. Dr. F. S. Russell (Visitor) suggested that there were already in existence a number of journals in which such special articles could be published, and Dr. Blegvad (Visitor) pointed out that the International Council for the Exploration of the Sea in their publications gave a bibliography of a number of papers on marine biology and oceanography. Dr. Sverdrup considered that it would be of great value to investigate the problem of how world-wide literature on this branch of science could be got together, and he suggested the appointment of a committee to go into the matter. Professor Proudman suggested that the Commission should nominate several biologists and should ask the Council of the Association d'Oceanographie Physique to include these biologists in the committee that is to be appointed by the association to consider the proposal of Dr. Green.

This proposal was adopted, and the following Biologists were nominated by the Commission :—

Professor Louis Fage,
Lieut.-Commander Lumby, and
Dr. Ruud.

It was resolved that the Commission could not support Professor Romanovsky's proposal.

OCEANOGRAPHIC ACTIVITIES OF THE U.S. COAST AND GEODETIC SURVEY 1939–1949

By Rear Admiral L. O. Colbert, Director, Washington, D.C.

The oceanographic activities of the Coast and Geodetic Survey in the Pacific area, between the years 1939 and 1949, embraced three fields—hydrographic surveying, tide and current work, and nautical charting.

The principal hydrographic operations were carried on in Alaskan waters. A total of approximately 244,000 miles of sounding lines were run covering an area of 154,000 square miles. Prior to World War II Coast and Geodetic Survey vessels in Alaska had completed charting a large percentage of the waters of south-eastern Alaska and had made good progress in charting south-western Alaska. With the outbreak of the war the waters in the vicinity of the Aleutian Islands became strategically important, and the bulk of the hydrographic work was concentrated there.

Since the close of the war these surveys have been extended, and hydrography has now been completed in an area extending 60 miles on either side of the island chain from longitude 170° E. to the general vicinity of Kiska Island. A comprehensive survey has been initiated in the Bristol Bay area and along the Arctic coast of Alaska, where little is known of the depths of water, the character of the ocean bottom, or the behaviour of tides and currents.

The programme of deep-sea sounding-lines across the Gulf of Alaska by Coast and Geodetic Survey vessels while *en route* to and from their west coast bases was interrupted during the war years. Work was resumed in 1945, and has since been extended into the north Pacific Ocean. This extensive project has added greatly to our oceanographic knowledge of the area. Many unknown submarine features have been discovered and more complete data obtained on known features, notably the Aleutian Trench. In 1947 an uncharted seamount was found in latitude 51° N., longitude 143° W., which rose to a depth of 460 fathoms from surrounding depths of over 2,000 fathoms.

Off the Pacific coast of the United States hydrographic operations were practically suspended during the war years. Since 1939 approximately 33,000 miles of sounding-lines were run covering an area of 6,500 square miles. Hydrographic surveys were started in the Midway Island area in 1941, but were abandoned after the attack on the Hawaiian Islands.

In the course of the hydrographic operations numerous observations were made for the determination of temperature and salinity of sea-water. In addition, magnetic stations were occupied and the data obtained have contributed to the maintenance of isogonic charts of the ocean areas.

Several notable developments in hydrographic techniques made during the past ten years will have significant effects on the collection of oceanographic data in the Pacific and elsewhere. Graphic recording fathometers were adopted by the Bureau in 1940 as standard equipment for hydrographic survey parties. This equipment greatly expedited operations in shoal waters. Greater accuracy in echo soundings are being achieved by improvements in the time-measuring device and in operational techniques.

Shoran, a wartime electronic development for pin-point bombing, has been adapted by the Coast and Geodetic Survey for locating a ship's position in hydrographic surveying at distances of 50 to 75 miles from shore. The first surveys using this method were made in the western Aleutians in 1945, and has since been extended to other areas. Shoran has completely replaced the former radio acoustic ranging method. Another electronic method, known as the electronic position indicator, has been developed by the Survey to extend offshore hydrographic surveys beyond the limits of Shoran. This equipment was tested under service conditions in 1947, and distances up to 225 miles from shore have been measured.

The new distance-measuring devices will make possible more rapid extension of offshore surveys and more accurate oceanographic investigations in the regions of the continental shelves and beyond.

Tide and Current Work

The programme of collecting, analysing, and publishing tide and current data for the Pacific area was considerably expanded since 1939. Two factors contributed to this stepped-up programme. The war in the western Pacific being largely amphibious in nature, our armed forces required information on tides and currents for their over-all planning. As a result, numerous tide gauges were established and current surveys conducted in strategic areas, and a large number of special predictions were prepared. The accumulation of tidal observations has been analysed harmonically and constants determined for 144 places in the Pacific Ocean.

Much of this material has now been incorporated into the tide and current tables. Special tide and current tables are still being published for the Philippine Islands as well as for Japan and China. For 1949 the tables, together with the regular tide tables for the Pacific and Indian Oceans, contain daily tide predictions for 104 places and tidal differences for about 2,500 places, as compared with 49 and 1,800 respectively for 1939. Daily current predictions have been added for thirteen places.

The second factor responsible for the increase in the tidal work of the Bureau has been the programme of co-operation with the Latin American countries, inaugurated in 1941, and with other Government agencies in the western Pacific. The Bureau is now maintaining forty-eight automatic tide gauges in the Pacific. The accumulation of tidal data will not only provide much-needed original information for the prediction of tides, but will contribute greatly to the development of tidal knowledge in the Pacific.

A comprehensive current survey of Puget Sound, using the newly-developed radio current meter, furnished the basic material for two recently published tidal current charts for the northern and southern parts of the Sound. A number of current surveys were made in San Francisco Bay and in Alaskan waters. A revised edition of Tidal Current Charts, San Francisco Bay, and a pamphlet based on five months of current observations in San Pedro Channel, California, were issued. Comprehensive current surveys of the various passes along the Aleutian Island chain and of the passages through the San Juan Archipelago in Washington are planned.

Since 1943 the Coast and Geodetic Survey has been systematically making observations for temperature and density of sea-water at most of its tide stations. Publications giving the results of these observations are revised every two years.

Studies are under way for the development of a general warning system for seismic sea waves. Three steps have thus far been taken: a chart has been published showing the time required for a seismic sea wave to reach Honolulu from an earthquake epicentre in the Pacific; a local sea-wave detector, which utilizes the arrival of the first part of the seismic sea wave for alerting the area, was developed and placed in operation at Honolulu and at Hilo ; and a chronological file of seismic sea-wave data has been set up. In addition to these steps, the warning system, when fully developed, will involve rapid co-operation on the part of seismological observatories, tide stations, and communication networks.

NAUTICAL CHARTS

The experimental chart, No. 5101A, which the Coast and Geodetic Survey published in 1939 for the southern California area has important significance in oceanographic studies. This type of chart is characterized by many depth curves which bring to light submarine features not readily discernible on the conventional type of chart where many soundings are shown, but only few depth curves. Practically all of the Pacific coast charts follow this new pattern and it is being applied to the charts in other areas where information is available for the accurate delineation of the submarine topography.

PAPERS PREPARED FOR PACIFIC SCIENCE CONGRESS

The two following papers were prepared for presentation :—

Tidal Investigations in the Pacific, by E. C. McKay.
A Seismic Sea Wave Warning System for the Pacific, by W. B. Zerbe.

UNITED STATES: DIVISION OF OCEANOGRAPHY, THE HYDROGRAPHIC OFFICE, UNITED STATES NAVY

THE following excerpts are taken from the annual report of the Hydrographic Office :—

Collection and Dissemination of Oceanographic Data

The oceanographic programme continued at an increased rate the implementation of the more or less routine tasks included in the programme. These tasks, in part, include the collection and maintenance of the files of basic oceanographic data ; compilation, analyses, and preparation of this data for inclusion in reports, manuals, and publications; standardization of the methods for observation and reporting of oceanographic information by both governmental and non-governmental agencies ; preparation of reports in answer to requests for oceanographic information from military and non-military activities ; participation, through procurement of equipment and personnel, in Navy-sponsored expeditions and representation on numerous committees and panels concerned with oceanography and related sciences.

Numerous new programmes were initiated. One such programme is concerned with oceanography and allied studies in high latitudes. Studies relating to physical characteristics, distribution, and movement of sea ice were started and are continuing. The development of new specialized equipment, rather than the modification of present equipment, was instigated ; codes and reporting forms to assist in standardization of methods of recording ice data were prepared and issued, and such related items as the preparation of an ice glossary, in several languages, were initiated.

Another programme of interest was the standardization of hydrographic and oceanographic observations aboard naval vessels. This programme has already resulted in considerable benefit to the Navy, this benefit resulting not only from more accurate data, but also from the greatly increased quantities of information pertaining to sonic soundings, horizontal and vertical sea temperature distribution, sea and swell, sea ice, aids and hazards to navigation, and harbour and port facilities.

Library Facilities.—The library has increased its collection of scientific and technical works, especially those pertaining to the field of oceanography and allied sciences. The library at present consists of over fifteen thousand publications, pamphlets, and periodicals on the subjects of geography, hydrography, oceanography, navigation, physics, and chemistry. In February, 1948, all branch Hydrographic Offices were equipped with modern " reference libraries " of the latest books and publications on navigation and related subjects, as a means of improving the services of the branch Offices to the Navy, the Merchant Marine, and the general public.

Oceanographic Surveys.—The first requisite for an understanding of the various oceanographic phenomena, such as currents, sea and swell, and temperature, salinity, and density distribution, is adequate geographic and seasonal records related to these phenomena. This necessitates a continuous programme of observation which must, of necessity, be conducted at sea. Every source of basic data must be exploited. As the Office did not have its own laboratory and ships for conducting these observations, other activities, both governmental and non-governmental, domestic and foreign, were called upon to supply these data.

The results of these programmes, in part for the collection and reporting of basic oceanographic data are indicated in the table below.

Source of Data.	Type of Data.	Quantity (Approximate).
Surface vessels of the U.S. Fleet ..	Bathythermograph records	4,000 records.
Submarines	Bathythermograph records	1,700 records.
Merchant Marine	Surface current, temperature, and sea and swell records	40,000 records.
Vessels of the U.S. Fleet ..	Sea and swell observations	1,500 records.

The records listed in the above table by no means represent the total of the data received. Arrangements were made for oceanographic technicians to accompany Navy-sponsored expeditions to the Arctic and other areas of strategic importance. The Hydrographic Office observers sent to the Antarctic in 1947–48 were trained in collecting oceanographic data. These technicians carred out a detailed and comprehensive programme of observations, and their results are embodied in reports submitted to this Office. In addition, privately-operated research vessels, both domestic and foreign, observed and reported many diversified types of oceanographic data.

Development and Procurement of Equipment.—In order that the basic oceanographic data may be collected in a most usable form and in the most expeditious manner, specialized oceanographic equipment is necessary. The Office played an active role in the development of new types of such equipment and in the improvement of existing equipment. Also, a comprehensive list of equipment and supplies, with the possible source of procurement, was compiled and furnished to interested activities.

Forty-three deep-sea reversing thermometers were received from Richter and Weise in Germany, and an order was placed for an additional seventy. The Woods Hole Oceanographic Institution completed their thermometer calibration chamber, the first of its kind in the United States, and all Hydrographic Office thermometers are now being calibrated. Some thermometers were received from Woods Hole Oceanographic Institution, after calibrated, and issued to United States Navy Electronics Laboratory for co-operative use.

Various other types of sampling equipment, including bottom samplers, Nansen bottles, bathythermographs, and sample bottles were procured for use aboard naval vessels by the technicians. Two hydrographic winches of special design, incorporating hydraulic control and a constant tension device were ordered. A new type of stream-lined oceanographic sounding weight was designed and four were ordered.

Considerable effort was expended in design, development, and procurement of equipment for use in the Arctic. Contracts were let for the manufacture of several pieces of this equipment, including a field kit for testing the mechanical properties of sea ice.

Contracts with Oceanographic Laboratories.—Because of the present limited personnel and the lack of facilities required for observations and research it was impossible to conduct all of the projects within the Office. Consequently a portion of the funds available for the oceanographic work were used to support contracts at the Scripps Institution of Oceanography, La Jolla, and the Woods Hole Oceanographic Institution, Woods Hole, Massachusetts.

A considerable quantity of basic data was procured by these contractual agencies, both by personnel aboard their research vessels and by their technicians designated to accompany Navy-sponsored expeditions. Specifically, studies concerned with the hydrography of the North Atlantic, which includes bottom sediments, temperature, salinity and density distribution, and transparency measurements; characteristics, distribution, and movement of sea ice; fog forecasting techniques; waste disposal at sea; Pacific Ocean biology and the deep scattering layer were received. A total of fifty technical reports was received from the contractors during the year.

In addition to the observational programmes undertaken by the contractual agencies, the procurement of oceanographic data is implemented by their development and construction of equipment. During fiscal 1948 current meters, bottom-sampling devices, water-sampling devices, and continuous recording equipment for salinity, temperature, and depth measurements were among the items under development or construction.

The bathythermograph slides received from units of the Fleet and other governmental and privately-sponsored surveys are processed by the contractors. A total of over ten thousand processed bathythermograph records was received by the Office during the year.

Compilation of Oceanographic Data.—Once the data has been received by the Office it must be processed so that it may be filed and be readily accessible for use during the preparation of charts, manuals, and reports. Some types of data, received in tabulated form, are filed without further processing. Other types of recorded information such as that on the sea and swell forms and the Special Observer's Logs are punched into IBM cards for ease of filing and sorting.

The bathythermograph records, which number approximately two hundred thousand, are photographic copies of the originals. During fiscal 1948 the entire collection of bathythermographs were refiled by global quadrant, one degree quadrangle and by month.

Bibliographic Files.—One important phase of the oceanographic compilation programme is the acquisition and maintenance of a bibliographic file. This file includes not only the card index, cross referenced to subject, author, and area, but also, whenever possible, copies of the technical papers and reports, either published or manuscript.

Oceanographic Publications.—The end products of the survey and compilation programmes are the publications. As the types of data concerned with the oceans cover many basic fields of science, the resulting publications are also varied, both in type and subject. Examples of these publications include current, sea, and swell and temperature atlases, sonar, bottom sediment, density and temperature charts; reports, for general or specific areas, relating to currents, sea, and swell, currents, sea ice, &c., and various other technical and popular studies relating to all phases of oceanography.

Oceanographic Conferences.—As this Office is responsible for all oceanographic work conducted by the armed forces it is necessary that close liaison be maintained among all activities concerned. These activities, in part, include the Research and Development Board, the Bureaus and Offices of the Navy Department, the Army and the Air Forces. Also other governmental agencies, such as Fish and Wildlife Service, the Coast Guard, and non-governmental activities such as the various oceanographic laboratories and universities, must be frequently consulted. The most practicable way to maintain this liaison and co-operation is through conferences of interested personnel. During fiscal 1948 personnel from this Office attended a total of 118 conferences which met in Washington, Baltimore, Seattle, San Francisco, Woods Hole, and other localities on oceanographic matters.

Liaison on Oceanographic Matter.—Through co-operation with other agencies, both governmental and non-governmental, domestic and foreign, the amount of oceanographic data received was considerably increased. Reporting forms were supplied to the Swedish research vessel the "Albatross"; close liaison was maintained between the Fish and Wildlife Service and the Division resulting in a mutual exchange of data; tidal information was procured from the Coast and Geodetic Survey. Considerable information was obtained from oceanographic laboratories and activities in foreign countries.

THE ALLAN HANCOCK FOUNDATION FOR SCIENTIFIC RESEARCH

By Irene McCullock, University of Southern California, Los Angeles, California

At the Allan Hancock Foundation for Scientific Research at the University of Southern California, Los Angeles, California, most of the emphasis will continue to be placed on marine biological research in the fields of Invertebrate Zoology.

Some oceanographic research under the direction of Dr. K. O. Emery and assistants will centre on the eleven partially closed basins off southern California in an attempt to find the mutual dependence of sea-water characteristics and diagenesis with the hope that knowledge of environments existing at present in the basins will lead to better understanding of the conditions of petroleum accumulations in the Los Angeles oil fields.

A thorough core sampling programme of the various deep basins on the Continental Shelf off southern California is planned in connection with oceanographic work. New coring apparatus is in process of construction and should be available for this work by the end of 1948.

Along with extensive programmes in the field of marine invertebrate research, the limited research programme in oceanography and sedimentation studies, much time and thought will be placed on the development of equipment, directly connected with the ship and otherwise, the possibilities of television from ocean bottom to the ship, and the use of a benthoscope for direct observation of ocean bottoms around the islands off southern California. Some time will be spent on developing more effective nets for obtaining animal populations, including fish.

THE PACIFIC OCEANIC BIOLOGY PROJECT

By Charles J. Fish, Woods Hole Oceanographic Institution

Except in Japanese home waters, Palau and Bikini, there has been relatively little research on the biology of pelagic ocean populations of the central and western North Pacific. There remains a dearth of data on the interaction of biological processes and the environmental factors involved in their production, distribution and fluctuations, particularly in tropical areas. Such major problems, involving multiple controlling factors, require the combined services of a group of experienced investigators in a carefully co-ordinated long-range programme.

Following the termination of the war a Pacific Science Conference in Washington, on 6th to 8th June, 1946, recommended to the National Research Council the organization of a Pacific Science Survey. Oceanic biology was one of the subjects proposed and endorsed by the Conference. However, as recommended, oceanic biology problems in the central and western North Pacific " . . . should not be attacked before a thorough survey has been made of the information accumulated by our own agencies during the war, gathered by our allies or contained in captured Japanese documents. The first step toward approaching many problems should, therefore, be an examination and critical analysis of that information." It was considered especially important that Japanese data be reviewed in the light of recent developments in marine biology in other countries.

The first phase of the programme was instituted on 1st September, 1946, by the Woods Hole Oceanographic Institution with a grant from the Office of Naval Research, the designated objective being to assemble and analyse available data and thereafter to formulate a comprehensive field programme. Subjects specified for attention were—

(1) Character and distribution of plankton as related to features in physical and chemical oceanography and to the natural resources of the sea;

(2) Distribution and growth rates of reef-building corals;

(3) Causes and occurrence of phosphorescent waters;

(4) Regional distribution and biology of fouling organisms;

(5) Character and prevalence of sound producing marine animals; and

(6) Poisonous or otherwise dangerous marine animals.

A staff of six marine biologists and technical assistants first compiled a bibliographic card index, with abstracts, of some ten thousand titles. A set of 4,098 Japanese nautical and oceanographic charts were next catalogued and titles translated. To further facilitate the use of Japanese material a glossary of Japanese hydrographic terms (approximately four thousand words) and a comprehensive Japanese oceanographic dictionary have been prepared by Rodney Notomi.

Analysis of data and preparation of reports on the assigned subjects are now well advanced. Five scientific reports have so far been completed :—

(1) " Sonic Fishes of the Pacific." by Marie P. Fish. Available data on sonic members of forty-two families of teleosts are presented with an extensive bibliography of literature on the subject. The seasonal and regional distribution of subsurface noises attributable to fishes have been charted from records in Submarine War Patrol reports.

(2) " Practical Aspects of Coral Reef Growth," by Gordon A. Riley. A consideration of the present status of knowledge on Pacific reef growth and the environmental factors involved, with a classified bibliography of pertinent publications.

(3) " Phytoplankton of the Western North Pacific," by Gordon A. Riley and Ruth von Arx. Quantitative distribution of plankton and certain of its environmental factors, including surface temperature, transparency, and the surface concentrations of phosphate, nitrate, nitrite, and silicate. The report is based largely on Japanese data which have been averaged by five-degree squares over periods of three months for charting purposes.

(4) " Fouling in the Western Pacific," by Louis W. Hutchins. The area treated in this report is somewhat larger than in others of the series, to permit incorporation of important data on the Hawaiian and Solomons – New Hebrides regions. Much of the information has been derived from a study of unpublished results of Navy-sponsored investigations and a large file of data on ship, net, and mine fouling acquired in the course of war-time operations.

(5) " Poisonous and Otherwise Dangerous Marine Animals of the Western Pacific," by Charles J. Fish and Mary C. Cobb. A review of inedible, venomous or ferocious species of coelenterates, molluscs, echinoderms, elasmobranchs, teleosts, and reptiles, based on published records and unpublished military documents.

The following reports are in preparation :—

(6) " Bioluminescence in the Western North Pacific," by Charles J. Fish. Regional and seasonal occurrence and the biology of the organisms involved.

(7) " Sonic Marine Mammals of the Pacific," by Marie P. Fish. Existing information on the production of subsurface noise by mammals, the character of the sounds produced, and distribution records charted from Submarine War Patrol reports.

(8) " Zooplankton of the Western North Pacific," by Charles J. Fish. Quantitative and qualitative analysis of available data on zooplankton correlated with environmental factors. To this end the methods of presenting the quantitative distributional data are being made as nearly uniform as possible with those used in the report on phytoplankton.

As originally planned, the comprehensive biological oceanography field programme, closely correlated with physical oceanography and high seas fishery research programmes now under development, would begin upon completion of the present studies. It is now evident, however, that before any major expansion in this field can take place new personnel must be trained. Provision is therefore being made for the training of a limited number of carefully selected graduate students for basic research in biological oceanography.

REVIEWS OF PACIFIC OCEANOGRAPHY

REPORT ON THE OCEANOGRAPHIC LABORATORIES OF THE UNIVERSITY OF WASHINGTON

By Thomas G. Thompson, University of Washington

The Oceanographic Laboratories of the University of Washington comprise the main laboratories situated on the campus of the University in Seattle and the field laboratories near the town of Friday Harbour on San Juan Island in Washington Sound.

The laboratories in Seattle are housed in a three-storied brick building, funds for the construction and equipment of which were provided by the Rockefeller Foundation in 1930, and are well equipped for research in the various branches of oceanography. A circulating sea-water system is maintained at a temperature of 9° c., the average temperature of the waters of Puget Sound.

The Friday Harbour laboratories are situated on a 480 acre tract with about two miles of shore-line. There are about a dozen buildings in the area, half of which are one-storied buildings of hollow tile construction and well equipped with all modern laboratory facilities. At the present time ten cottages with housekeeping conveniences are under construction for use of scientists and their families throughout the year. Much of the activities of the field laboratories centre around the summer quarter, when about one hundred persons are in residence. This number includes members of the staff, advanced investigators from a number of institutions, and graduate students, and also members of families. Tents are used for living quarters in the summer, and a central building serves as a mess hall.

The professorial staff consists of thirteen persons, two of whom devote full time to the work of the laboratories, one being the resident scientist at Friday Harbour. The other eleven members, including the director, are also affiliated with one of the following departments: botany, chemistry, fisheries, geology, meteorology, microbiology, physics, or zoology. The research interests of the staff and their graduate students centre around various problems in oceanography as related to their several specialties in the fundamental sciences.

With the entry of the United States into World War II many of the staff were called into service or to other war duties. The Seattle laboratories were taken over by the United States Navy, and the Friday Harbour laboratories were changed to a training school for the United States Coast Guard. The research vessel, "Catalyst," which had been especially constructed for oceanographic work from funds granted in 1932 by the Rockefeller Foundation, was converted to a patrol vessel for use in Alaskan waters by the Coast Guard.

After the war it was two years before the laboratories began to operate again to capacity. An Act of the United States Congress provided for the replacement of the research vessel, but currently two small vessels are charted, the plans for the research vessel still being only on paper.

An oceanographic survey of Puget Sound, Washington Sound, and the Strait of Juan de Fuca is being conducted under the supervision of Dr. Clifford A. Barnes, Associate Professor of Oceanography. This survey is a continuation of a series of long-range studies of the inland waters of the State of Washington and the coastal system. The objectives of this survey are to obtain a rigorous picture of the circulation within the Strait of Juan de Fuca and Puget Sound and the exchange of these waters with contiguous water masses, including the open ocean; to assess the effects on the system of external influences such as tides, meteorological conditions, and river run off; and, where possible, to interpret the internal conditions, including the physical, chemical, and biological regimes in the light of the overall physical oceanography. Drs. Alfred C. Redfield and William L. Ford, of the Woods Hole Oceanographic Institution, participated actively during the summer of 1948 in the survey.

Research effort has been largely concentrated on obtaining three-dimensional circulation patterns using the Salinity-Temperature-Depth Recorder (S-T-D). This device, developed at Woods Hole, will continuously record the temperature of the sea-water and depth of submersion of the sensitive element when towed or lowered from a ship. Although the reliability of the measurements is somewhat less than obtained from normal water-bottle techniques it is adequate to establish local gross circulation patterns and to define temporal changes that could not be readily observed by other means. The salinity of local waters varies from about $34^0/_{00}$ near the bottom of the Strait of Juan de Fuca to near zero in the upper layers off mouths of rivers and provides a most useful index for determining the limits and tracing the movement of local water masses.

Two fisherman type craft of 50 ft. and 55 ft. in length, operating out of the laboratories at Seattle and Friday Harbour, have been used for field-work. Continuous surface records have been made for approximately 4,000 miles cruising on seventy-eight trips, and in excess of one thousand lowerings have been made for vertical structure. Surface circulation patterns for the period July to September have been charted for flood and ebb tides in Washington Sound between the Straits of Juan de Fuca and Georgia and in the immediately adjacent waters of these Straits. An insight has been obtained of vertical structure and processes in this primary mixing zone of Fraser River effluent with ocean water. During September the area of investigation was extended seaward in the Strait of Juan de Fuca to within 30 miles of the open Pacific, and also to the head of Puget Sound. During the period October to December investigations were largely confined to the Puget Sound-Hood Canal system with numerous measurements being made in the entrance to Puget Sound, Admiralty Inlet, a critical constriction and mixing zone which restricts water exchange with the open Strait.

The local circulation pattern is characterized by an incoming supply of relatively dense saline water upwelled from moderate depths of the Pacific entering the coastal system on the bottom of the Strait of Juan de Fuca and by a surface current of relatively fresh water from river run-off and precipitation flowing seaward on the surface. Wind and oscillating tidal effects are superimposed on the circulatory system to accelerate mixing and vary the net water exchange. Prime mixing zones normally occur at or near vertical or lateral constrictions in the channels, mixed water flowing seaward superficially on the ebb and landward at depth on the flood. The irregular nature of the submarine topography, and effect of earth's rotation, act on the moving water masses to give apparently anomalous density distribution and complicated flow patterns in which currents of different strata vary in both magnitude and direction.

Model studies of critical areas are being initiated to supplement field observations. Although prototype conditions cannot be exactly scaled in any practical model it is expected that these studies will give a continuity and a flexibility not readily obtained in the field.

Dr. C. L. Utterback, Professor of Physics, has been concerned with the radium analysis of sea-water, bottom samples, and organic material. He is extending his studies to include uranium and possibly thorium. The extensive radium analyses which have been made by him and other investigators and some very meagre data from questionable uranium analyses indicate a considerable departure from radioactive equilibria. Thus the amount of radium in sea-water, $0{\cdot}8 \times 10^{-16}$ grams per gram of sample would be supported by $0{\cdot}24^{-9}$ grams of uranium per gram of sample. The indications are that sea-water contains four to five times as much uranium as is necessary to maintain the radium balance. It is improbable, in the case of sediment washed by water, that radioactive equilibrium exists, but the unbalanced can be determined. The distribution of radioactive material in marine plant and animal matter will probably give information as to the reason for the unexplained ratio of the radioactive products of disintegration. While the concentration of radium is such that rather accurate analyses have been made by the ionization method, the quantities of uranium present are extremely minute and new techniques are being developed for its determination.

Considerable attention is being given to the nature of fogs, particularly in the Seattle area, by Dr. Phil E. Church, Professor of Meteorology. Serial ascents of a delicate low altitude meteorograph below a tethered balloon are made hourly during foggy conditions. The results show that in radiation fog the lapse rate changes from inversion to wet adiabatic as the fog thickness increases vertically. Plans are being initiated for the investigation of a number of characteristics of the summer fogs which occur off the Washington coast. He is also planning to make extensive observations with the bathythermographs during the course of a year in the north-east Pacific to determine detailed thermal structure in the upper layers of ocean water and compute the heat loss and gain in opposite seasons.

Dr. Rex J. Robinson, Professor of Chemistry, and the writer are engaged in studies on the distribution and methods of analysis for a number of the elements occurring in sea-water. At the present time refinements in the methods for the determination of potassium, strontium, and fluorides are receiving attention. A paper on the distribution of various nutrient salts, dissolved oxygen as well as the temperatures and salinities of the waters of Puget Sound, Washington Sound, and the Strait of Juan de Fuca over a ten-year period is in preparation. A study is also in progress on the preferential adsorption of certain ions in sea-water in freshly forming ice crystals. Paired with this investigation is another dealing with a phase rule study on the deposition of the salts in sea-water by frigid concentration. Dr. Robinson is also occupied with a study of the determination and distribution of phosphorous in organic compounds dissolved in sea-water.

Present methods for the determination of plant pigments lack sensitivity and fail to give estimations of the different pigments present. A method using a small sample is being developed and can be standardized for comparison of results. The Tswett chromatographic method is being applied by Mr. Francis Richards. Small amounts of pigment are concentrated and compared with similarly adsorbed pigments of known amount. Preliminary results indicate that amounts of pigment too small for accurate colorimetric comparisons may be compared in this way. A modification of the Harvey pigment standards, in which not only the concentration of the two coloured inorganic salts, but also their ratio to each other, is varied, offers a standard of greater versatility than the original Harvey standards. However, it appears that it will be better to report pigment values as percentage absorption in well-defined bands of the visible spectrum. This method is being developed for a chemical estimation of phytoplankton.

In the field of biochemistry, Dr. Earl R. Norris, Professor of Biochemistry, and his students have been engaged in several series of researches dealing with nutrition, vitamins, enzymes, and metabolism of marine organisms. Ready for publication are papers dealing with the purification and properties of the pepsin of halibut, albacore, yellow fin tuna, and blue fin tuna; the occurrence of arsenic in marine organisms; the composition of marine algæ and the seasonal occurrence of laminarin in brown algæ of the Puget Sound area, including the enzymetic hydrolysis of the carbohydrates of algæ; and the nutritional requirements of young salmonoid fish.

A long-range programme is being initiated by Dr. W. H. Blaser, Associate Professor of Botany, dealing with the distribution and characteristics of the algæ of the Puget Sound and Washington Sound areas, together with considerable attention to physiological studies of some of the marine plants.

Dr. Arthur W. Martin, Professor of Zoology, is continuing his investigations on the circulatory phenomena of fishes. Blood volumes have been described in a number of species, great changes taking place in the blood volume during pregnancy of viviparous fishes. The characteristics of the hemoglobin of the young of viviparous fishes have been shown to conform to those of fetal mammals. The dynamics of fluid exchange between the circulating blood and the tissue fluid are at present being investigated.

Dr. Dixy Ray, Assistant Professor of Zoology, is examining early developmental processes in the coelenterates, the current form being the scyphistomae of *Cyanea capillata*. Her students are investigating new mesozoans from the urinary tract of *Polypus hongkongensis*, the morphology of the tectibranch *Phyllaplysia taylori*, and the classification of intertidal chitons.

Dr. A. H. Whitely is pursuing work upon the mechanisms of energy transfer in the developing egg, with special emphasis upon the utilization of high-energy phosphate bonds. He is now in a position to follow the overturn of tagged phosphorus atoms in the metabolic cycle of the common invertebrate eggs.

At the Friday Harbour laboratories continuous meteorological and tidal records, generally obtained by mechanically recording devices, are under the supervision of Dr. Emery S. Swan, Assistant Professor of Oceanography and Resident Scientist, together with quantitative studies of the seasonal variation of the temperature, salinity, and various nutrient salts of the sea-water near the laboratories. A study of the shell secreting organs of the serpulid worms has just been completed and currently he is engaged in a statistical investigation of the relationship of growth indices to environmental factors for several species of clams.

Dr. Erling J. Ordal, Associate Professor of Microbiology, is working on (1) the morphology and physiology of bacteria occurring on marine plants and animals, and (2) bacteria which cause disease in fishes, particularly salmonoid fishes.

The School of Fisheries of the University of Washington has under construction on the Seattle campus a large fisheries laboratory, the site of which is immediately adjacent to that of the Oceanographic Laboratories. Thus located, considerable exchange of information is anticipated with Dr. Richard van Cleve, the Acting Director, and Dr. A. C. DeLacy, representative of the School of Fisheries on the oceanographic staff.

The Library of the University of Washington is among the larger libraries of the United States. Through its inter-library loan service any volume or journal is readily obtainable. It also maintains a branch library at Friday Harbour which is housed in a special building.

The publications of the Oceanographic Laboratories comprise the Publications in Oceanography in which longer or more detailed articles appear, and the Reprint Series. It is the policy of the laboratories to encourage as much as possible publication of the results of oceanographic research in the standard scientific national journals. A large number of reprints of articles so appearing are purchased for the Reprint Series and used for inter-library exchange.

Summary of Discussion

A short discussion followed, in which Dr. Deacon asked whether it was true that a commercial process was available for the extraction of potassium from sea-water. Dr. Thomson replied that one project was under way in the United States, but that he had no information as yet as to actual results.

OCEANOGRAPHIC CONTRIBUTIONS OF MARINE BIOLOGICAL LABORATORIES ON THE PACIFIC COAST OF NORTH AMERICA

By Robert C. Miller, California Academy of Sciences, San Francisco

The investigation of the sea is a difficult and expensive undertaking. Only a few institutions can afford to maintain a research vessel of sufficient size to carry on work for weeks or months in the open sea. It is to be hoped that the number of such institutions may be increased and the funds available to them augmented. In the meantime, however, it is desirable to emphasize the role in marine investigations of seaside laboratories not equipped for full-scale oceanographic work.

The marine biological laboratories, often housed in modest quarters and nearly always with inadequate funds, have made a large number of significant contributions to our knowledge of the sea, and several of them have in the course of time developed into laboratories devoted primarily to oceanographic research.

That has, in fact, been the history of all the oceanographic institutions on the Pacific Coast of North America. The Scripps Institution of Oceanography of the University of California began its history as the Scripps Institution for Biological Research. The University of Washington Oceanographic Laboratories became successor in interest to the Puget Sound Biological Station. In 1911 the University of Southern California opened a small laboratory on a pier at Venice, California, where summer classes were carried on until it was destroyed by fire in 1921. A continuous thread of events can be traced from this modest beginning to the present extensive programme of the Hancock Foundation.

It is not anticipated that all or most of the marine biological laboratories will develop into oceanographic institutions. Some of them may; but in any case all of them are in a position to contribute significantly to the sum total of our knowledge of the sea. It is the purpose of this paper briefly to review the nature and scope of such contributions by laboratories on the Pacific Coast of North America, other than those definitively engaged in oceanographic work.

Historically the California Academy of Sciences, established in 1853, was the earliest centre of marine research on the Pacific Coast, and its Proceedings, publication of which began in 1854, contain various early contributions to ichthyology, malacology, meteorology, and the study of ocean currents—one of the latter, the Davidson Current, being named after George Davidson, President of the Academy from 1872 to 1887. Since the turn of the century the Academy has conducted a number of sea-going expeditions, with vessels obtained for a limited time either with Academy funds, by private philanthrophy, or through the co-operation of State or Federal agencies. The Steinhart Aquarium, erected in 1923, provides facilities for the study of the life-history, behaviour, and physiology of marine organisms.

The Hopkins Marine Station of Stanford University established in 1892, is regarded as a centre of research in physiology and experimental biology, rather than oceanography. It has, however, made numerous substantial contributions to the latter science. As examples, one may mention the work of Jordan and Gilbert on marine fishes, Fisher on Asteroidea, Bolin on both littoral and deep-sea fishes, G. M. Smith on marine algæ, and Skogsberg on temperatures in Monterey Bay in relation to currents.

The Pacific Biological Station, Nanaimo, B.C., was established by the Biological Board of Canada in 1908, mainly as a centre of fisheries research. In that connection it has had occasion to carry on a great deal of fundamental research on the life-history and ecology of marine organisms, both vertebrate and invertebrate. In recent years its work has extended increasingly into the field of physical oceanography, as evidenced by the recent publication of six volumes of mimeographed reports on temperature, salinity, and density at several stations from Dixon Entrance to the Strait of Juan de Fuca. Tully's studies of the mixing of fresh and salt water in coastal areas have opened up a field that may profitably be explored by institutions lacking facilities for deep-sea work.

The Bureau of Marine Fisheries of the California Division of Fish and Game, whose laboratory at Terminal Island was established in 1921, has expanded rapidly into sea-going investigations, and one or more of its vessels are presently being equipped for full-scale oceanographic work in connection with the investigation of the California sardine. It is likely that the corresponding State agencies in Oregon and Washington, conducting excellent work in the investigation of marine fisheries, will find it increasingly necessary to expand into the oceanographic field.

The United States Fish and Wildlife Service is conducting large-scale investigations in the Pacific area. It is not possible in a report of this scope even to detail those being carried on along the Pacific Coast of North America. The Service has been active in the investigation of substantially all important Pacific Coast fisheries, and has given attention to improvement of methods, gear, &c., for the collecting of the eggs and larvæ of pelagic fish, and the collection of other plankton organisms. One should not omit reference to the important work of the U.S.S. " Albatross," which spent much time between 1901 and 1917 in Pacific Coastal waters. The survey of San Francisco Bay, 1912-1913, is outstanding.

The Laguna Beach laboratory of Pomona College, established in 1911, the Coos Bay laboratory, established in 1937 under the Oregon State System of Higher Education, the Pacific Biological Station established by the College of the Pacific at Dillon's Beach, California, in 1947, and the laboratory established the same year at Anacortes, Washington, by Walla Walla College are primarily teaching laboratories for the training of undergraduate students. Doubtless the research aspect will be increasingly developed as time goes on. However, it should be remarked that the training of undergraduate students in marine science is in itself an important end, and not at all to be minimized. From these laboratories may come many oceanographers of the future.

In conclusion, it may be stated that many of the problems of oceanography relate to the interaction between sea and land. Littoral ecology is a field of major importance, in which the marine biological laboratories are in a position to make a unique contribution. Every item of information contributes to the sum total of our knowledge of that vast, amazing complex that is the sea.

SUMMARY OF DISCUSSION

That oceanography was at present being treated from the point of view of the whole range of the subject was emphasized by Dr. Foerster, who remarked that Marine fisheries, for instance are being developed at the Pacific Biological Station, Nanaimo, as well as other oceanographical and biological projects, although handicapped by shortages of personnel and equipment supply.

Dr. Hubbs pointed out that Dr. Miller's review was intended to be exclusive of the work of the University of Washington Oceanographic Laboratory and the Scripps Institution, which would be reviewed later.

A tribute to the large numbers of small fishing craft, and to the invaluable help continually received from fishermen was paid by Dr. Frances Clarke. Dr. Johnson concluded with an appreciation of the work of the U.S. Navy, particularly the Navy Electronics Laboratory.

REPORT ON THE MARINE RESEARCH WORK OF THE ALLAN HANCOCK FOUNDATION

By John F. Kessel, School of Medicine, Los Angeles

[*Abstract*]

The biological survey of the Eastern Pacific from San Francisco to San Juan Bay, Peru, which has been due to the able assistance and co-operation of Captain Hancock with his "Velero III," has established to date approximately 1,650 shore and dredging stations. This work is shallow water on the whole with the major part being done in depths under 100 fathoms. Much time has been consumed in getting the large collections properly housed in Hancock Hall, in negotiating and transferring to the Pacific Coast the taxonomic reference library of the Boston Society of Natural History, and the training of advanced graduate students to begin the study for taxonomic monographs of the faunas and floras of the area. Eighty-two separate reports, ranging from descriptions of new species to monographs, have been published.

Summary of Discussion

Dr. Emery supplemented Dr. Kessel's general review with some remarks of interest to marine geologists on the bottom sediments and on the physiography of the area. He described a series of basins, eleven in all, extending outwards beyond the coast, each with different bottom depths and different grades of sediment. Those nearest the shore had coarsest sediments and were widest and flattest, with increasing irregularity and fineness of sedimentation on proceeding seawards. The history of these basins was thought to be of importance in the interpretation of the Los Angeles basin. Work was described on the intersection of the salinity and temperature curves in the various basins, and the sediments in the Los Angeles basin were stated to be of particular importance from the point of view of oil prospecting.

OCEANOGRAPHIC DEVELOPMENTS IN THE HAWAIIAN AREA

By Robert W. Hiatt, University of Hawaii

Historical Introduction

It is my purpose to present a review of oceanography in the Hawaiian area and to examine critically impending developments which, for the first time in our history, portend concentrated analyses of a localized, subtropical island area.

Oceanography as a science had its inception in Hawaii one hundred and seventy years ago when Captain Cook and his staff of scientists visited the Archipelago near the end of the eighteenth century. For the next half-century a series of notable explorers and investigators visited Hawaii and returned to Europe with collections of the flora and fauna and copious notes on hydrographic features of interest to mariners. The first intensive investigation was made by Americans of the U.S. Exploring Expedition of 1838–42. This was followed by the first great oceanographic expedition to circumnavigate the globe, the "Challenger" Expedition of 1873–76. In 1902 the U.S. Fish Commission steamer "Albatross" visited Hawaii for the primary purpose of investigating the deeper waters about the Archipelago. Thus, although the waters reach great depths about Hawaii, it is as Edmondson (1939, 593) states, " . . . an obvious fact that we began investigation of the marine fauna of the Pacific on the bottom and worked up."

In November, 1947, the Swedish Deep-Sea Expedition, under the direction of Dr. Hans Pettersson, visited Honolulu and occupied several stations in the vicinity of the Archipelago. The U.S. Navy has collected many bathythermograph records and depth soundings in the Hawaiian region which are being processed by the Scripps Institution of Oceanography.

SHORESIDE LABORATORIES

One of the most significant developments in oceanography in Hawaii is the establishment of the Hawaii Marine Laboratory. This laboratory, under the general control of the University of Hawaii but operated in close co-operation with the University of California, was made possible by the generosity of Edwin W. Pauley and four associates, owners of Coconut Island in Kaneohe Bay. Available on Coconut Island now are several excellently constructed tidal ponds varying in length from 40 ft. to over 600 ft. These ponds are walled with cement or coral blocks and are separated by an elaborate system of metal screen gates. On shore are several banks of sunken tanks and glass-fronted aquaria which range in capacity from 100 to 10,000 gallons. Excellent docking facilities and a marine railway capable of handling boats up to 50 ft. in length are part of the physical plant.

To supplement these unrivalled outdoor facilities the present net house on the dock will be enlarged and divided into laboratory rooms. Plans have been made and partly implemented to install the most modern equipment to facilitate the most exacting research. We trust that the importance of this station will expand and that its benefactors will increase their interest commensurate with the growth of the undertaking.

Plans are being formulated for the erection of a large laboratory and administrative centre for the vast Pacific Oceanic Fishery Investigation established to conduct research on the pelagic fishery resources in the central Pacific area. This laboratory will be situated on the campus of the University of Hawaii where close co-operation between the scientific staffs of both organizations will be effected. The now universally recognized relationship between basic oceanographic studies and applied fishery programmes will be implemented by enmeshing an intensive oceanographic programme with the fisheries investigation. Laboratory facilities, floating facilities, and a large technical staff of oceanographers will thus be stationed in Hawaii.

FLOATING FACILITIES

The " Salpa " is owned and operated by the University of Hawaii and is the station vessel of the Hawaii Marine Laboratory. A diesel-powered, 46 ft. boat, the " Salpa " is outfitted for in-shore and short off-shore work around the main Hawaiian Islands. It carries a winch to operate plankton nets and dredges to medium depths, the latest type of both compressed air and self-contained diving apparatus, and fishing gear for several types of fishing operations. A feature of great utility is a 500-gallon live-well, through which sea-water is circulated at 100 gallons a minute, which serves to return specimens to the laboratory alive.

The " Makua," operated by the Division of Fish and Game of the Territorial Board of Agriculture and Forestry, is a 65 ft. diesel craft which has been converted to a general purpose fishery and oceanographic vessel with a 3,000 mile cruising range. It carries winches for deep-sea dredging and net hauls as well as for both bathythermograph observations and light plankton hauls. Sufficient Nansen bottles and reversing thermometers to initiate the programme of physical oceanography are on hand. The " Makua " also carries an improved type of live-well in which the water may circulate at 400 gallons a minute.

The conversion of the three vessels to be operated by the Pacific Oceanic Fishery Investigation in the pelagic fishery investigation is in progress. One of this trio of vessels will be converted into an oceanographic research vessel. The remaining vessels will be outfitted mainly as fishing craft. This fleet, in addition to the vessels mentioned above, will comprise a concentrated supply of research vessels in Hawaii and the central Pacific which should provide abundant physical facilities.

RESEARCH PROGRAMME

The current research programme can best be presented in three phases, although all are closely integrated :—

Physical Oceanography.—The Scripps Institution of Oceanography has issued recently completed reports on the analysis of bathythermograph records and echo soundings taken in Hawaiian area during and subsequent to the war. These reports describe the diurnal and seasonal variation in sea temperature and vapour pressure, the variation in salinity, and the bottom contours for several miles out to sea in the vicinity of Kaneohe and Hilo.

A long-period wave-recorder or tsunami recorder, designed at the Scripps Institution, has been installed in the Hawaiian Islands. This device suppresses by hydraulic filtering short-period wind-waves and swell and very long-period waves such as the tides. This instrument has a maximum sensitivity of periods of one hour and is designed to cut out tides of a mean range of 15 ft. It will record waves primarily in the period range from six minutes to six hours, and of amplitude of less than 1 in. as well as tsunamis of amplitude of 6 ft. to 8 ft. The study of such records will lead to results of considerable geophysical interest, and an instrument in the Hawaiian Islands is particularly desirable because of the frequency of occurrence and magnitude of tsunamis there.

With the completion of the Hawaii Marine Laboratory the University's research plans will be implemented. These comprise a study of those aspects of oceanography peculiar to this subtropical region. Broadly speaking, the physical oceanographic programme may be called a study of the ecology of the near-shore and off-shore waters around the islands of Hawaii and the study is readily divided into three parts : (1) ecology of the in-shore waters (*i.e.* primarily the waters inside the reefs of Kaneohe Bay), (2) ecology of the transition region beyond the reef, (3) ecology of the oceanic waters.

These subdivisions are established for the following reasons : the very near-shore waters have their endemic faunal and floral populations but these waters are also nursery grounds for much of the food of pelagic fishes. Within many of the near-shore areas there is a rapid exchange of water with the outside, and it appears possible that a considerable amount of the organic matter present off the reef area is produced on and inside the reef. The region directly beyond the reef is another ecological subdivision, distinct in character from the oceanic water at greater distances from the shore. How far the near-shore effects reach is unknown. Similarly, it is not known if the off-shore waters are uniform or if variable conditions related to external influences such as variable winds or upwelling are commonly encountered. A brief outline of the programme contemplated at the Hawaii Marine Laboratory is outlined in *Pacific Science* (Hiatt, 1948, 67).

The Hawaiian Tuna Packers Corporation is entering the field of fundamental oceanographic research where results are likely to lead to immediate applications beneficial to the industry. Scheduled for installation on their research vessel in the very near future is a submarine detector unit and oscilloscope with which they plan to study the sounds made by skin friction of pelagic fish. This apparatus will record vibrations up to 100,000 cycles, and it is hoped that sufficient differentiation can be observed between the several species of tuna and other tuna-like fish so that the detection of individual species by the oscilloscope record will be possible. The practical applications of such a device are obvious where at least four species of tuna occur, some of which are much more desirable than others.

A second project of great significance involves the use of sonic means to herd fish either by repelling or attracting them. Considerable data on the response of fresh-water fish to sounds of various frequencies are available, but to my knowledge little or nothing is known about this phase of behaviour of pelagic species.

Interaction of Biological Processes and Their Controlling Factors.—Experience of the last few years has demonstrated conclusively that fundamental oceanic biology, concerned with the interaction of biological processes and the multiple controlling factors involved in the production, distribution, and fluctuation of marine populations requires the combined efforts of a group of experienced investigators participating in a carefully co-ordinated programme of basic research. A programme of this nature forms the essential liasion between physical oceanography and fisheries biology, but distinct in scope and in personnel requirements. Results of such studies provide the basis for regional productivity, a subject grossly misunderstood in tropical and subtropical oceanic waters.

An investigation of the production of food by plankton in Hawaiian waters was initiated this year by oceanographers at the University of Hawaii in co-operation with fishery biologists at the University and the Division of Fish and Game. Further co-operation and considerable expansion of the programme is anticipated when the staff of the Pacific Oceanic Fishery Investigation is established at the University. The overall objective of the study is to analyse the production of food, by plankton, for higher animals in both the neritic and oceanic provinces of the sea adjacent to Hawaii as related to the complete environment. First, an investigation of the zoo-plankton production involving both qualitative and quantitative studies will be made, with the latter aspect resolved in terms of organic material per unit volume of water. The study will embrace the food chains consisting of microplankton, macroplankton, and the food of fish as related to geographic, seasonal, and bathymetric distribution. Second, an investigation of the geographic, seasonal, and bathymetric distribution of the phytoplankton will be made. Third, an investigation of the currents, "fertilizer salts," oxygen concentration, and the penetration of light, all factors which influence photosynthetic activity in the water, will complete the project.

This undertaking is of great significance both to the fundamental concepts of oceanography in the tropics and to studies of commercial fisheries. It will coincide with the programme recommended by the Pacific Science Conference (*Pacific Sci.*, 1 (1) 59, 1947), with the programme of physical oceanography to the initiated at the Hawaii Marine Laboratory (Hiatt, 1948), and with the pelagic fisheries investigation to be undertaken by the Pacific Oceanic Fishery Investigation in the central Pacific.

There is neither sufficient staff nor funds available at present to launch the complete study, but a "pilot operation" to define major trends for later investigation was initiated this year. We expect it to show whether there is a marked variation in the plankton seasonally, bathymetrically, or geographically; to produce many of the larvæ of fish and invertebrates important in piecing together life-histories now being studied; to indicate what food organisms are available to pelagic fish; and to assay the contribution of the reef and shore fauna to the pelagic realm surrounding the Islands.

Other active research projects which dovetail into this major study include (1) a study of the relation of the reef and shore fauna to the economy of the neritic and oceanic regions, (2) a study of the life-histories of fish having pelagic larval and post-larval stages, (3) a study of the life cycles of invertebrates important in the food-chains leading to fish of commercial importance, and (4) a study of the food and feeding habits of pelagic fish in the Hawaiian area.

Applied Oceanography.—Aside from naval uses, applications of oceanographic information have been and are being made principally in fishery biology. Four agencies are co-operating closely in carrying out this phase of the work. The Co-operative Fisheries Research Staff of the Territorial Division of Fish and Game and the University of Hawaii has been engaged in various aspects of fishery research for the past three years. Present projects comprise (1) a study of the biology of the tuna baitfish (*Engraulis purpureus*) in which the distribution, population trends, reproductive cycle and potential, localized endemism (racial studies), age and growth, food and feeding habits, and methods of catching and holding are receiving most attention, (2) a study of pollution in Hilo Harbour which has virtually removed this port as a tuna fishing centre because of the rapid mortality of baitfish held in bait wells under present conditions, (3) a study of experimental trolling techniques for tuna in which deep trolling in relation to the thermocline is being tried for the first time, (4) a study of the occurrence of egg, larval, and post-larval forms of the tunas in the high seas of the Hawaiian area, (5) a morphometric study of statistically proven characters of Hawaiian tunas to ascertain the racial composition of the stock and to compare Hawaiian tuna with tuna, reputedly conspecific, in other sections of the Pacific, and (6) several studies on invertebrates, including ecological succession on developing coral reefs, the sponges of Hawaii, and the snapping shrimps of Hawaii. This latter study may prove of considerable value in demonstrating that Hawaii is the most suitable area for more detailed studies of the role of the snapping shrimp in the production of underwater noise in the sea (Johnson, *et al*, 1947).

Many fishing-vessels in Hawaii are installing recording fathometers for spotting schools of fish at various levels above the bottom. Phenomenal catches have been made using this instrument as a seeker. The sonic research vessel of the Hawaiian Tuna Packers is being equipped with modern devices to analyse schools of fish horizontally and vertically by echo sounding, and should experiments prove the practicability of speciating tuna by skin friction noises and herding them by sonic beams, a new era in catch methods will be ushered in.

The extensive programme of the Pacific Oceanic Fishery Investigation will include a considerable amount of fundamental as well as applied physical and biological oceanography.

The staff of the U.S. Weather Bureau in Honolulu has been active in devising means of forecasting swell and wave heights by analysing daily weather maps. Thus far they have been highly successful, and on several occasions warnings have been broadcast to operators of small craft and to occupants of homes near the tide line of impending danger to equipment in time to effect measures for safety.

Bibliographic Analyses of Oceanography in the Pacific.—Of considerable importance in establishing and assessing research programmes on oceanography in the Pacific is the exhaustive analysis of literature and unpublished documents on Pacific oceanic biology which is being carried out under Navy contract at the Woods Hole Oceanographic Institution. When the project is completed a firm basis for planning future investigations will be available.

Several members of the staff of the University of Hawaii are engaged in translating from the Japanese Utinomi's *Bibliographica Micronesica* (1944). Sections dealing with invertebrate zoology, oceanography, and limnology are nearing completion. The chordate section including that on fish has been completed and published by Fisher (1947). The translated bibliography is expected to be published by the University of Hawaii Press.

HAWAII AS A LOCALE FOR INVESTIGATIONS IN TROPICAL OCEANOGRAPHY

Space will not permit me to annotate as fully as I would wish some of the more fundamental problems which, when solved, will enable us to understand the tropical seas as well as we do our temperate waters. With respect to the general biological economy of tropical and subtropical seas we must study (1) the quantities, rate of growth, and food complexes of the organisms present, (2) the role of bacteria in various locations in the warm sea, (3) the tropical and subtropical plankton compared with temperate plankton in regard to organic content, metabolic rate, seasonal fluctuation in abundance and position bathymetrically, and its efficiency factor in foodchains.

Many vexing problems in the distribution of the Indo-Pacific fauna eastward will not be solved until we learn more about the ecology of the larval phases of littoral species, the span of their larval existence, and the ocean current system responsible for their transportation. I need not point out the great need of taxonomic studies on the marine fauna and flora of central Pacific areas.

Of monumental importance is the need for an accurate analysis of the scattering layers or false bottoms found so abundantly at depths of a few hundred fathoms in many areas of the Pacific. The most recent accounts of vast stretches of such layers are reported by the staff of the Swedish Deep-Sea Expedition aboard the "Albatross" (Pettersson, 1948). Scattering layers with rough borders which return echoes characteristic of comparatively large and densely packed organisms were found repeatedly when crossing the bands of convergence bordering the equatorial countercurrent. Below these areas of convergence cores taken with the piston core sampler (Kullenberg, 1947) varied from nearly pure radiolarian ooze to nearly pure globigerina ooze, indicating strips of highly productive ocean area. That this reflective layer may be related to a vast, untapped deep sea fishery is by no means outside the realm of probability (Chapman, 1947 ; Hahn, 1948 : 104 ; Pettersson, *op. cit.*).

In regard to physical oceanography the effects of oceanic islands on currents, upwelling, and regional productivity are rather easily studied in Hawaii. Studies on penetration of light in clear oceanic water and studies on submarine photography are especially applicable. Various aspects of submarine geology associated with volcanism and erosion are easily accessible for investigation.

We are aware that an efficacious programme in oceanography resides in a carefully co-ordinated effort in which many agencies with experienced personnel and specialized equipment participate. We look to the newly organized U.S. Committee on the Oceanography of the Pacific to provide the guiding hand in devising a co-ordinated approach to the vast problem.

Thus we recognize a twofold responsibility in Hawaii—first, to undertake portions of the programme for which we have personnel and equipment ; and, second, to provide working space and facilities for personnel of co-operating agencies. With the assurance that the University and associated institutions in Hawaii are vitally interested in mid-Pacific oceanography and are striving to further research in this sphere to the extent of their facilities, suggestions for co-operative efforts with other institutions in the Pacific are indeed welcome.

REFERENCES

CHAPMAN, W. M. (1947) : The Wealth of the Ocean. *Sci. Mon.*, 64 (3), 192–197.

EDMUNDSON, C. H. (1940) : The Relation of the Marine Fauna of Hawaii to That of Other Sections of the Pacific Area. *Sixth Pac. Sci. Cong.*, Proc., 3, 593–598.

FISHER, H. I. (1947) : Utinomi's *Bibliographica Micronesica :* Chordate Sections. *Pacific Sci.*, 1 (3), 129–150.

HAHN, J. (1948) : Woods Hole Oceanographic Institution. *Turtox News*, 26 (4), 98–104.

HIATT, R. W. (1948) : Preliminary Note on the Oceanographic Program of the Hawaii Marine Laboratory. *Pacific Sci.*, 2 (1), 67–68.

JOHNSON, M. W. ; EVEREST, F. A. ; and YOUNG, R. W. (1947) : The Role of Snapping Shrimp (*Crangon* and *Synalpheus*) in the Production of Underwater Noise in the Sea. *Biol. Bul.*, 93 (2), 122–138.

KULLENBERG, B. (1947) : The Piston Core Sampler. *Svenska Hydr. –Biol. Kom. Skrifter* III, 1 (2), 1–4°.

PETTERSSON, H. (1948) : The Swedish Deep-sea Expedition. *Pacific Sci.*, 2 (4), 231–238.

UTINOMI, H. (1944) : *Bibliographica Micronesica/Scientiæ Naturalis et Cultus*. 208 p. Hokuryükan Pub. Co., Tokyo.

SUMMARY OF DISCUSSION

Dr. Johnson inquired whether marine geology was to be included within the Hawaii project. Dr. Hiatt replied that there was no submarine geologist at Honolulu at the present time, but that it was hoped to provide facilities in the programme for geology as soon as sufficient interest developed. In answer to a query about wave recording, it was stated that tide measurements were to be made, but that there was no particular work about to be commenced on waves.

REVIEW OF CANADIAN PACIFIC OCEANOGRAPHY SINCE 1938

By JOHN P. TULLY, Pacific Biological Station, Nanaimo

INTRODUCTION

Until 1943 oceanography on the Pacific Coast was sponsored by the Fisheries Research Board, and was directed entirely to fisheries objectives. From then until 1947 the facilities were diverted to naval purposes under the direction of the National Research Council. In 1946 the Joint Committee on Oceanography was formed by pooling the requirements and allotments of the Fisheries, Navy, and National Research Council in this field of research. Atlantic and Pacific Oceanographic Groups are established with headquarters at the respective biological stations, and vessels manned and operated by the Navy. Technical assistance and equipment is provided by the National Research Council. This interdepartmental co-operation has greatly increased the horizon and capabilities of Canadian oceanographic research.

H.M.C.S. "CEDARWOOD," A CANADIAN OCEANOGRAPHIC RESEARCH SHIP

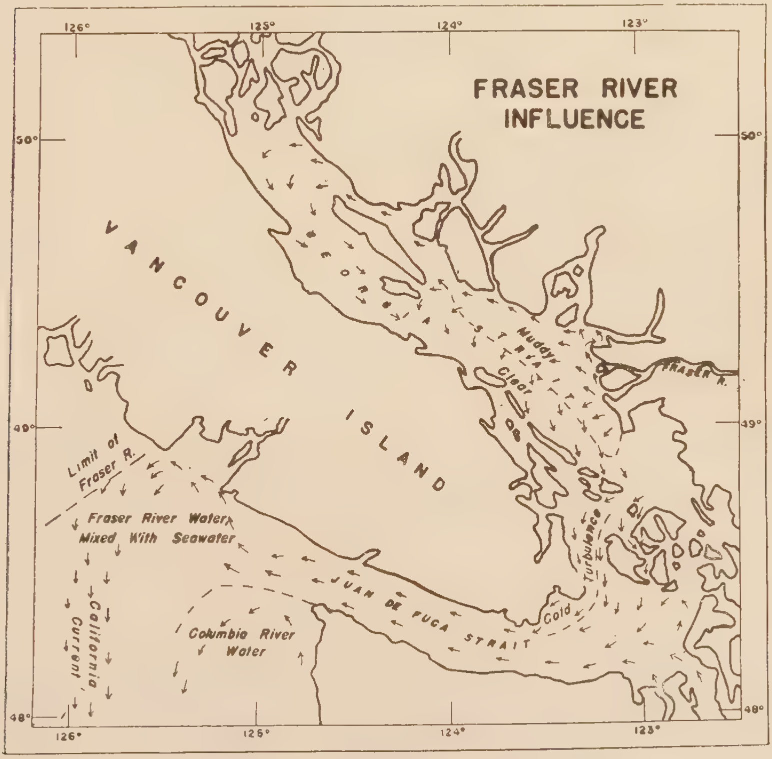
To date most Canadian oceanographic studies in the Pacific have been located in the coastal regions and the inland seaways, and in consequence have been primarily concerned with the influence of fresh water in the sea, and related phenomena.

THE FRASER RIVER PROJECT

The influence and limits of the Fraser River in the sea has been the subject of investigation by Canadian and United States oceanographers for the past twenty years. These include the studies by the University of British Columbia, the University of Washington, the Pacific Biological Station, and the Canadian Navy. These data are being consolidated into a coherent digest by the Oceanographic Laboratories at the University of Washington and the Pacific Oceanographic Group.

The Fraser River outflow system contains one of the wealthier fisheries of the Pacific coast, and is the subject of considerable fisheries research. Further, the system provides a wide variety of oceanographic conditions with virtual temperature gradients representative of Arctic, Temperate, and Tropical seas. As such, it is of primary importance as a region for naval underwater research.

It was found that the Fraser River spreads out in Georgia Strait, most of the water moving anti-clockwise around that basin, mixing with the underlying sea-water *en route*. It passes to the sea, through a


FRASER RIVER INFLUENCE
126°
125°
124°
123°
50°
49°
48°
VANCOUVER ISLAND
GEORGIA STRAIT
Muddy
Clear
FRASER R.
Limit of Fraser R.
Fraser River Water Mixed With Seawater
California Current
Columbia River Water
JUAN DE FUCA STRAIT
Cold
Turbulence

FRASER RIVER INFLUENCE

region of extreme turbulence in the Washington Archipelago, where the 30 ft. to 40 ft. depth of brackish surface water, originating in the Fraser River outflow, becomes mixed with about 600 ft. of dense sea-water, provided by tidal circulation from the zone of up-welling along the ocean coast. Evidence of fresh water from the Fraser River is lost in this process, so that the outflow from Juan de Fuca Strait is more saline than the approaches to many of the smaller drainage systems in the vicinity.

The outflow from Juan de Fuca Strait is evidently maintained by a hydraulic head established in Georgia Strait and Puget Sound. Emerging from the strait it veers to the right and moves northwestward along the Vancouver Island shore. This stream is subject to annual variation related to the fresh-water discharge from the Fraser River and the seasonal winds, which are south-east in the winter and north-west in the summer. Within a distance of approximately 30 miles the energy of the northwestward flow is dissipated in eddies, the water is absorbed into the California current off-shore, and moves southward in the Oceanic circulation.

This research was interrupted by the Alberni project (see below) and the war. Preparation of the report for publication is now under way.

THE ALBERNI PROJECT

In 1939 it was required to predict the state of pollution that would result from a proposed sulphite-pulp mill to be established at the head of Alberni Inlet on the west coast of Vancouver Island. This seaway is typical of many of the "fjord type" inlets along the British Columbia and Alaska coast, which, oceanographically speaking, are two-dimensional estuary systems.

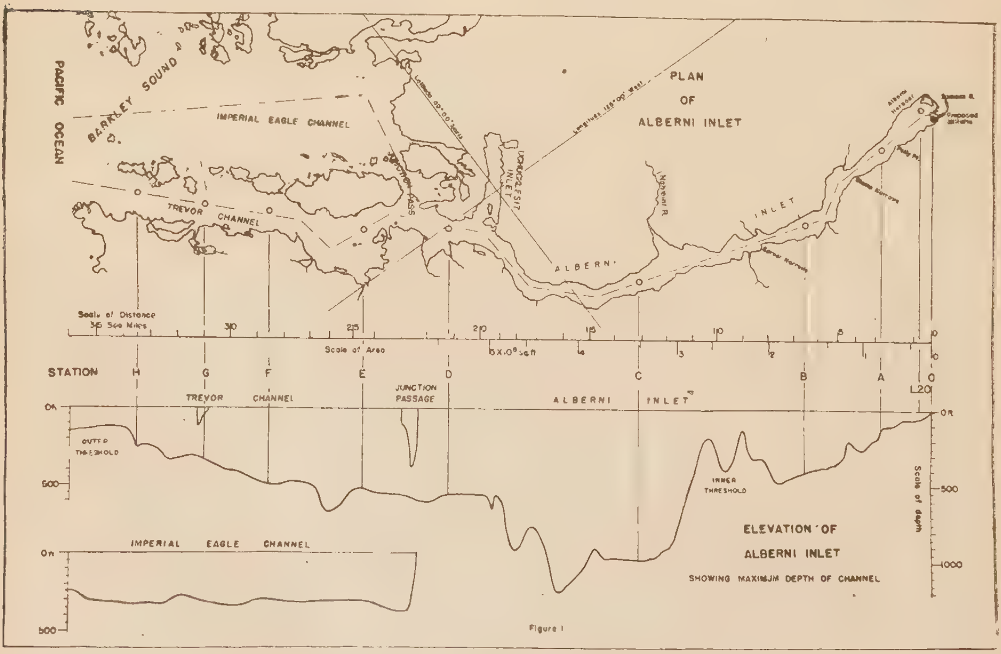

PACIFIC OCEAN
BARKLEY SOUND
IMPERIAL EAGLE CHANNEL
TREVOR CHANNEL
Latitude 49°00' North
Longitude 125°00' West
PLAN
OF
ALBERNI INLET
UCHUCKLESIT INLET
Nahmint R.
ALBERNI INLET
Alberni Harbour
Somass R.
Proposed Millsite
Scale of Distance
Sea Miles
35
30
25
20
15
10
5
0
Scale of Area
5X10⁶ sq.ft
4
3
2
1
0
STATION
H
G
F
E
D
C
B
A
0
L20
TREVOR CHANNEL
JUNCTION PASSAGE
ALBERNI INLET
0ft
500
OUTER THRESHOLD
INNER THRESHOLD
0ft
500
1000
Scale of depth
ELEVATION OF
ALBERNI INLET
SHOWING MAXIMUM DEPTH OF CHANNEL
IMPERIAL EAGLE CHANNEL
0ft
500

Figure 1

PLAN AND ELEVATION OF ALBERNI INLET

It was apparent that the only pollution character of consequence was the oxygen demand of the waste sulphite liquor. If pollution was to be avoided it was necessary that the mill sewage should be displaced from the mill-site to the open sea before the dissolved oxygen content of the inlet waters was lowered by 50 per cent.

An intensive oceanographic investigation showed that the fresh water from land drainage moved isostatically seaward. Due to tidal energy it mixed with the under-lying sea-water *en route* to form a brackish upper zone. The thickness, properties, and the rate of seaward displacement of water through this zone were quantitatively related to the discharge of the principal river in the inlet. There is a converse movement of ocean water in the zone immediately below this, which provides the sea-water to be mixed into the upper zone. Any fresh water transferred downwards is held isostatically adjacent to the boundary and preferentially returned to the upper zone in the mixing process. Consequently all fresh water leaves the inlet by way of the upper zone, and none accumulates in the lower.

Below the level of the threshold there is a deep zone, in which movement is generated by frictional transfer of velocity from the overlying middle zone.

A hydraulic model of the head of the inlet was built, in which the tide, the fresh and sea-water, and the winds were represented. From this it was learned that the outflow of the river was a jet function, whose stream diverged until it occupied the whole width of the inlet. Seaward of this limit of divergence there was no transverse salinity gradient, and the system was effectively two-dimensional. The tidal and isostatic flow characteristics in the head of the inlet, and the course of the effluent from various sewer outlets were studied in this model, and confirmed by oceanographic observations and float experiments in nature.

From these studies it was evident that if the pulp-mill sewage were diluted with all the wash water from the mill so that it entered the upper zone of the inlet at approximately the density of fresh water it would remain in the upper zone and be continually displaced seaward. This approach to the problem permitted the fresh water in the inlet to be regarded as a tracing solution, indicating the behaviour of the proposed effluent. It was concluded that no sewage would appear in the middle or deep zones, which would therefore be free of pollution. If sewage were dumped in these zones it would accumulate and eventually cause pollution.

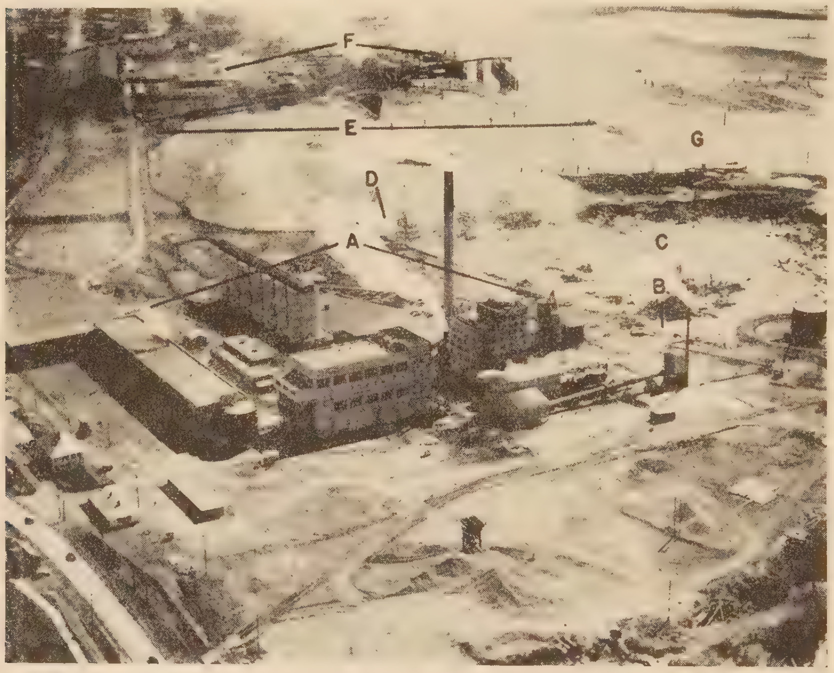
The degree of pollution (P) was defined as the ratio of oxygen demand of the pulp-mill sewage (BOD) to the dissolved oxygen supply (DO). The tolerable rate of discharge of sewage into the upper zone was arbitrarily defined as the amount whose oxygen demand would not exceed 50 per cent. of the oxygen supply. The pollution was considered tolerable when

$$P = \frac{BOD}{0{\cdot}5\ (DO)} \leqq 1$$

This provided a quantitative definition of pollution which could be evaluated.

The normal oxygen content of the incoming fresh and sea-water was observed, and the oxygen supply in the upper zone was evaluated from the observed proportions of each, and their rate of displacement through the inlet. The oxygen demand of the pulp-mill sewage was estimated from the known rate of oxidation of waste sulphite liquor and its concentration and age at successive intervals between the head and mouth of the inlet. The latter quantities were predicted from the relations between river flow and the quantities of sewage discharge, the proportion of fresh water in the upper zone, and the displacement.

It was concluded that the sulphite mill would be tolerable while the discharge of the principal river into Alberni Inlet exceeded 1,600 cubic feet per second. The discharge was less than this during three months of the year, implying that mill operation would have to be curtailed, the sewage stored over the period, or the river discharge maintained by storing water when the river was high. Industry solved the problem by building a *sulphate* mill whose pollution potential was within the tolerable limits of the seaway.



THE BLOEDEL, STEWART, AND WELCH SULPHATE PULP MILL AT THE HEAD OF THE ALBERNI INLET

Legend:

A. Pulp-mill buildings.
B. Sewer outlet.
C. Settling pond (Lupsi Cupsi Point).
D. Overflow to log pond.
E. Log pond.
F. Sawmill.
G. Somass River mouth.

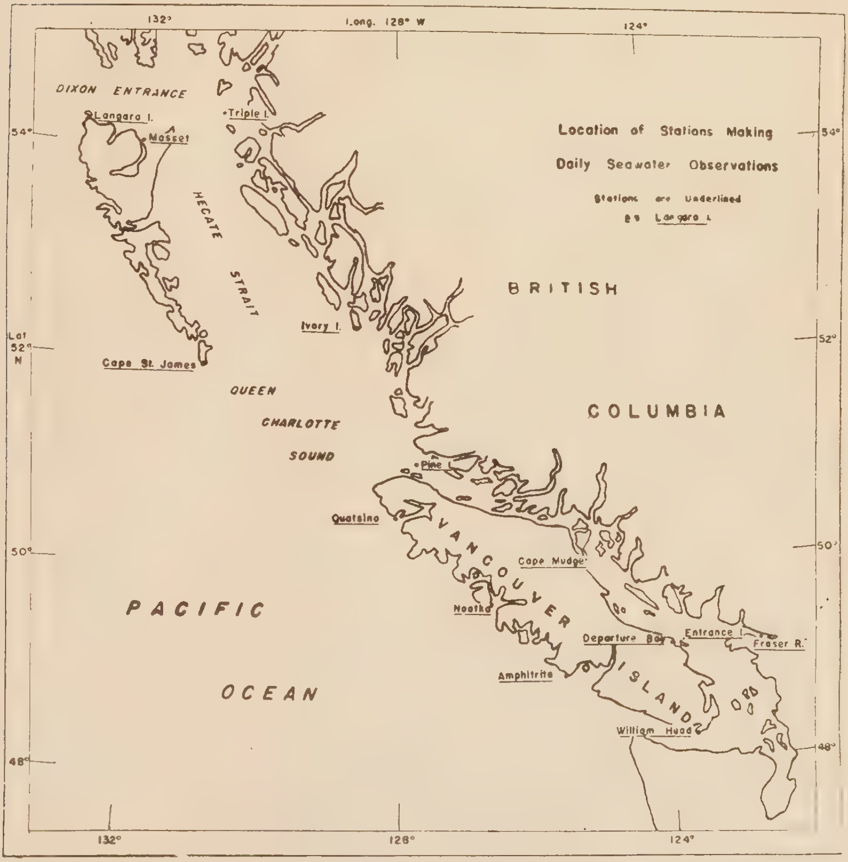
This installation has been checked, and the degree of pollution is found to be well within the predicted limits. At the same time further expansion is limited by the remaining margin of tolerance between the existing and limiting degree of pollution.

It is to be remarked that in this case there was no problem arising from pulp fibres settling out, because the bottom of Alberni Inlet does not contribute to a commercial fishery.

This research is unique in that it undertakes to evaluate quantitatively the characteristics of an estuarial seaway in terms of river discharge, which is a readily observable monitoring factor. It provides a quantitative measure of pollution and shows how it may be evaluated from a knowledge of the properties of the pollulant, and the oceanography of the system. Finally, it offers a precedent for the prediction of the probable degree of pollution from industrial development, which in turn permitted adjustments to be made before the fishery was damaged.

The field-work was done between 1939 and 1942, but development of the data was interrupted by the war and was only completed in 1948. The research is reviewed in detail in three papers, which are to be published as a bulletin of the Fisheries Research Board of Canada (Ottawa) :—

(1) Oceanography of Alberni Inlet. J. P. Tully.
(2) Prediction of Pulp Mill Pollution in Alberni Inlet. J. P. Tully.
(3) A Hydraulic Model of Alberni Harbour. J. P. Tully, H. J. Hollister, R. L. Fjarlie, and W. Anderson.


132°
Long. 128° W
124°
DIXON ENTRANCE
Langara I.
Masset
Triple I.
54°
Location of Stations Making
Daily Seawater Observations
Stations are Underlined
as Langara I.
HECATE
STRAIT
BRITISH
Ivory I.
Lat 52° N
52°
Cape St. James
QUEEN
CHARLOTTE
SOUND
COLUMBIA
Pine I.
Quatsino
VANCOUVER
50°
Cape Mudge
PACIFIC
Nootka
Departure Bay
Entrance I.
Fraser R.
Amphitrite
ISLAND
OCEAN
William Head
48°
132°
128°
124°

British Columbia

CHATHAM PROJECT

At the present time the Pacific Biological Station is making an intensive investigation of the sock-eye salmon fishery associated with the Nass and Skeena Rivers. These are large rivers (2,500 to 250,000 cubic feet per second discharge) entering the inland seaway (Chatham Sound) near the boundary between British Columbia and south-eastern Alaska. A proportion of the salmon fishery occurs in Chatham Sound beyond the geographic limits of either river. An intelligent study of the fishery in the sound requires a knowledge of the influence and variations of the river in that area. The oceanographic problem is to determine the course and influence of these two rivers in the region, from the time of maximum river discharge (May) to the minimum (September) and the variations introduced by the prevailing winds and tidal cycle.

The field investigation has continued from 10th May to 10th September, and a preliminary report is in preparation.

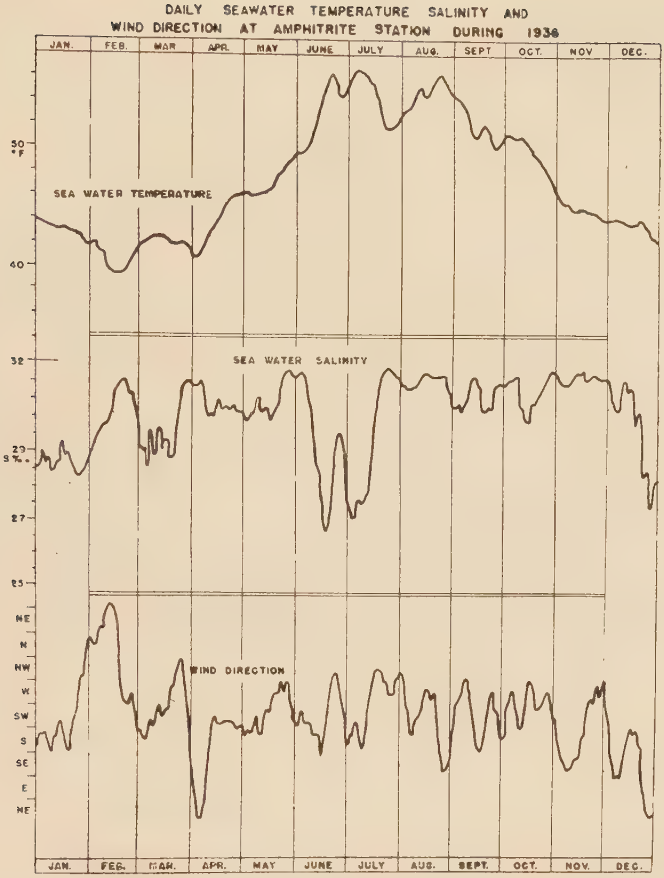
LIGHTHOUSE PROJECT

A programme of daily observations of the sea-water temperatures and salinities was initiated on the Pacific coast of Canada in 1917 with one station. This has been increased at intervals, until the present total of eleven stations was reached in 1939. Most of the observations are made from coastal lighthouses, which explains the project designation.

The seasons are shown in the temperature data, and the integral effects of land drainage are shown in the salinity records. The small fluctuations are attributed to wind effects, since off-shore winds cause upwelling and a consequent decrease in temperature and increase in salinity. On-shore winds have the converse effect. The duration of any combination of conditions is indicated by corresponding steady states in the records.

Oceanographic surveys are tedious and costly undertakings which cannot be repeated indefinitely, and from which the conclusions usually are not available before the observed situation has passed. However, it may be assumed in most cases that the oceanographic state is determined by the season, weather, tide, and runoff whose integral effect is reflected in the conditions at one point in the region. Therefore oceanographic surveys are usually undertaken to observe type states in terms of the controlling factors, and the conclusions related to the appropriate lighthouse observations. This allows the recurrence of the observed state to be recognized from these data alone—that is, the lighthouse data serve to identify the conditions under which occasional oceanographic observations are made, their duration, and frequency of repetition. The daily observations provide a complete calendar of events in the coastal ocean and seaways, by which present data may be made applicable to the past and future.

It is the purpose of this investigation to accumulate these records as reference data for all other investigations in the Canadian coastal seas, to determine their significance as submarine climatological indices, to determine their relations, if any, with the success of coast fisheries, to evaluate annual cycles and trends, and geographical differences. Their use has been somewhat delayed by the War, but this process of examination is begun, and studies based on the data may be anticipated.



Daily Seawater Temperature

The data are being published in mimeographed volumes which may be obtained on application to the Director, Pacific Biological Station, Nanaimo, B.C.

Observations of Sea-water Temperature, Salinity, and Density on the Pacific Coast of Canada

Volume	I :	1914 to 1934 inclusive	..	Now available.
,,	II :	1935 to 1937 inclusive	..	,,
,,	III :	1938 and 1939 ..	..	,,
,,	IV :	1940 and 1941 ..	..	,,
,,	V :	1942 and 1943 ..	..	,,
,,	VI :	1944 and 1945 ..	..	,,
,,	VII :	1946 and 1947 ..	..	,,
,,	VIII :	1948 and thereafter to be issued in annual volumes.		

H.M.C.S. "EHKOLI," A CANADIAN OCEANOGRAPHIC RESEARCH SHIP

PLANS FOR AN OCEANOGRAPHICAL EXPEDITION IN THE SOUTH PACIFIC, 1950–1952

By ANTON F. BRUUN, Zoological Museum, Copenhagen

SUMMARY OF DISCUSSION

PROFESSOR YONGE inquired whether it was hoped to bring back any deep-water material alive. Dr. Bruun replied that cool acquariums were to be installed, but that it was in general hopeless to try to secure pelagic material in an undamaged living state, since the nets filled with siphonophores and other coelenterates which killed the delicate planktonic animals. It was, however, hoped to keep benthal invertebrates alive. The question of alcohol and formalin preservative supplies was going to be difficult, but freezing methods has been suggested for preservation.

In answer to Dr. Shepherd's question whether it was proposed to take bottom cores at great depths, Dr. Bruun announced the full co-operation of Dr. Pettersson, who had made a piston available. It was stated further that the three Scandinavian nations would in all probability agree to maintain a joint international research vessel.

Dr. Hubbs wished to know whether it was proposed to concentrate entirely on bottom fauna or whether also very deep bathypelagic hauls were projected. It was stated that on this expedition only 10 per cent. of the hauls were to be taken at lesser depths than 1,000 metres of cable. The remaining 90 per cent. were to be bottom hauls and bathypelagic at over 1,000 metres. The type of net proposed was to be a three-boarded otter trawl. As to the problem of getting it down to the required depths, it was not thought that this would cause great dificulty. No trouble had been experienced in the "Albatross" expedition, and on this occasion the wire weighed as much as 18 tons. Checking the depth of the net was discussed, for it was pointed out that the deep sea may not have an even bottom, but may show many irregularities which echo-sounding would be able to detect.

THE PACIFIC CRUISE OF THE SWEDISH DEEP-SEA EXPEDITION

By HANS PETTERSSON, Goteborg

(Communicated by Anton F. Bruun)

ON 27th August, 1947, the Swedish Deep-sea Expedition on board the four-masted motor schooner "Albatross" (1,450 ton d.w.) started from Balboa for the Pacific part of its circumnavigating cruise(1). Our equipment, including the long "piston-core" samplers (Dr. B. Kullenberg)(2), the special Bofors depth-charges, exploding at 300–3,500 fathoms, with surface hydrophones and oscillograph or wire-recorder for recording deep sediment echoes (Professor W. Weibull)(3) had been tested with good results from the Government research ship "Skagerak" during an experimental cruise to the western Mediterranean in 1946(4). During our first Atlantic crossing, Madeira–Martinique, long cores had been successfully raised from great depths, and the thickness of the sediment carpet measured. The ship, prior to the start, had been converted into a floating laboratory with cabins for a science and technical staff of ten to twelve, spacious laboratories for different purposes, workshop, aquarium, special cool-storage for the sediment cores, &c. In the fore hold the large electrically driven deep-sea winch, capable of hoisting a load of up to 10 tons with a maximum speed of 100 metres per minute, together with a wire drum holding up to 12,000 metres of wire rope, had been installed. In the aft hold the diesel-electric plant energizing the winch with 140 k.w. was placed. Other winches on deck included a "series-winch" for water-sampling and reversing thermometers with 9,000 metres of 4 mm. wire rope, a cable winch for subsurface light measurements, &c. A special feature was the recording echograph, especially made by Marine Instruments Co. of London, which, under favourable conditions of wind and swell, drew continuous records of the bottom profile to within 1 or 2 fathoms, down to depths exceeding 4,000 fathoms.

The very heavy gear used made it advisable to lay the course largely within the equatorial calms, avoiding as far as possible latitudes beyond 20° North and South. This, on the other hand, called for air-conditioning of the cabins and laboratories in order to keep the staff efficient in the warm and moist climate met with. The itinerary had also been chosen so as to minimize the risk of being hampered in our work by hurricanes, typhoons, and adverse monsoons. Actually very few working days were lost through bad weather.

The Pacific cruise included four complete sections across the counter-equatorial current and its neighbourhood where frequent oceanographic stations down to the bottom and still more frequent temperature measurements in the upper layers, made by means of a bathythermograph, were carried out, affording unique material for future dynamic analysis. The echographs from these crossings gave evidence of reflecting layers indicated by diffuse " false bottoms ", in moderate depths, between 50 and 150 fathoms generally, which had a tendency of moving upwards towards the night. In some cases they apparently consisted of shoals of fish, in others, possibly, squids or else densely packed planktonic organisms. For lack of proper gear no samples could be taken. They appear to be associated with the strips of divergence—*i.e.*, upwelling water, rich in nutrient salts, which border the counter-equatorial current. The bottom samples taken by means of the corers, up to 16 metres in length, gave evidence in the same region of multiple stratification, noticed already from the " Challenger " cruise. Probably the equatorial current system has become displaced in latitude by changes in atmospheric circulation, accompanying the variations from glacial to interglacial epochs.

An interesting but rather unfortunate fact was the highly irregular bottom profiles met with here as well as in the Atlantic and the Indian Oceans, where a perfectly flat bottom is rather the exception than the rule. Moreover, where a perfectly level bottom occurs, it sometimes consists of an extensive lava-bed, covered by a thin veneer of sediment. Both circumstances repeatedly led to loss of instruments. The echo-sounding of the sediment thickness gave considerably smaller distances between the sediment surface and the reflecting layers beneath the sediment (presumably basaltic bedrock) both in the Pacific and the Indian oceans (maximum 300 metres) than the far higher values found in the Atlantic (up to 2,500 metres).

A total of sixty cores was raised from great depths (maximum 7,800 metres in the south part of the Mindanao Deep) with a maximum length of an individual core of 16 metres. Once completely investigated by mechanical, chemical, mineralogical, spectroscopic, radioactive, and biological analyses, these extracts from the " records of the deep " may be expected to yield interesting information on the past history of the central Pacific Ocean along our course, extending back in the Tertiary Age.

By means of a special water-bottle of large capacity (25 litres), samples of sea-water from different depths were collected for radium analysis (by precipitation with barium-sulphate) and for fluorescence analysis on uranium. The disturbed balance between uranium and radium in sea-water due to the precipitation of ionium(5) to the ocean bottom together with ferric hydroxides is probably the main cause of the surprisingly high radium content of many deep-sea deposits, especially of the Red Clay. Incidentally, the ionium affords a clue to the dating of the different strata from radium measurements. Measurements of submarine light in different spectral regions were carried out, partly by means of rectifying cells, down to 200 metres, partly by means of a submarine camera, down to 500 metres (Drs. N. G. Jerlow and F. Koczy). Near the surface measurements were also carried out on the ultraviolet component of submarine daylight. The frequency of suspended particles in different depths was measured by the Tyndall method.

The study of the large material collected during the cruise, with a total core-length from all the three oceans of 1,640 metres, will occupy several specialists in Sweden and also in other countries for at least five years. Liberal grants for this work are being put at our disposal, covering also the editing and publishing of a special report from the Royal Society of Goteborg. It is our hope that the new technique, which has now passed through crucial tests, will be used also by other nations on the vast and almost unbroken field of research offered by the deep ocean bed, its morphology, its stratigraphy and geochemistry, and its biology. During our cruise the latter subject was reserved for the last three months' cruise in the Atlantic Ocean, where deep-sea trawlings were made under the supervision of Dr. O. Nybelin, from the Natural History Museum of Goteborg, assisted by Dr. Kullenberg, who also mastered the coring operations with his sampler.

It appears that in the coming geophysical and biological work in great ocean depths one of the most important fields is the central Pacific Ocean centred round the Hawaiian Islands and Tahiti. Honolulu seems to be designed to become the centre of this research. The most important problems are, according to my notion :—

A. The chronology of the deep-sea sediments using radioactive and biological methods (analysis of foraminiferal shells)(6), possibly also volcanic ash-horizons, cosmic spherules, and, near islands with intense vegetation, pollen analysis.

B. The prevalence of lava beds in great depths and other signs of submarine volcanic activity.

C. The morphology of the bottom surface and of the substratum beneath it as revealed by echo-soundings, preferably by depth charges exploding *below* the sediment surface.

D. The temperature gradient in the deep sea bottom (one of the most important tasks of modern geophysics according to Professor Jeffereys, of Cambridge).

With regard to the last point it had been my intention to measure the geothermal gradient at various points along the route, for which purpose a special geothermometer, 11 metres in length and registering the difference in temperature between the surrounding sediment in this depth and the isothermal bottom water above it, had been constructed. Owing to repeated failures of the clockwork to work at the very low temperatures met with only two attempts both in the equatorial Pacific were successful. Both afforded unexpectedly high values of the geothermal gradient—viz., 22 and 26 metres per 1° centigrade respectively, which would imply a higher value of the geothermal current in the ocean bed than on the continents (possibly another indication of latent submarine volcanism). It would be rash to draw any inferences from these two isolated values until more material has been calculated by the same or by other methods.

Finally, it should be mentioned that the expedition doctor, J. Eriksson, of Eskilstuna, Sweden, a keen naturalist, made botanical excursions on the different islands where the "Albatross" touched, like James Island in the Galapagos Group, Nukuhiva in the Marquesas (where borings in a peat bog on the rarely visited Tovii Plateau were carried out by Dr. G. Arrhenius, geologist to the expedition), on Tahiti and on Ternate where the Pacific phase of the cruise came to its end on 26th January, 1948.

LITERATURE

(1) PETTERSSON, H.: "A Swedish Deep-Sea Expedition." *Proc. R. Society*, B. Vol. 134, p. 399, 1947.
(2) KULLENBERG, B.: "The Piston Core Sampler." *Svenska hydr. biol. Kom : s Skrifter*, Bd. 1 H 2, 1947.
(3) WEIBULL, W.: "The Thickness of Ocean Sediments Measured by a Reflexion Method." *Medd. Oceanogr. Inst. Goteborg*, 12, 1947.
(4) PETTERSSON, H.: "The Swedish Expedition to the Western Mediterrean, April–May 1946." *Bull. Inst. Oceanographique Monaco*, n : o 919, Oct. 25, 1947.
——— a.o.: "Three Sediment Cores from the Tyrrhenian Sea." *Medd. Ocean. Ibst. Goteborg*, 15, 1948.
(5) ——— "Manganese Nodules and the Chronology of the Ocean Floor." *Medd. Oceanogr. Inst. Goteborg*, 6, 1943.
(6) PHLEGER, FRED. B., JUN.: "Foraminifera of a Submarine Core from the Caribbean Sea." *Medd. Oceanogr. Inst., Goteborg*, 16, 1948.

REPORT OF WORK CARRIED OUT SINCE 1939 IN THE JAVA SEA BY THE LABORATORY FOR INVESTIGATION OF THE SEA, BATAVIA

BY J. D. F. HARDENBERG, BATAVIA

THE work done by the Laboratory for Investigation of the Sea at Batavia came to a complete standstill during the Japanese occupation, and has even now not yet reached this pre-war standard due to the lack of equipment and personnel.

Much of the instruments for oceanographic work have been lost or irreparably damaged, and we still have no vessel at out disposal to do work at sea, though just now I am trying to raise the funds to get two ships which, when they have arrived, will survey the whole Indo-Australian Archipelago, which for practical matters will be divided into a western and an eastern half.

In the first place salinities will be measured and charted during the different monsoons, in order to get in the course of years a more or less accurate survey of the currents between the islands. This, of course, is already roughly known and can be found in any sailing direction, but experience has shown us that details are very imperfectly known among the many channels, and these details have proven to influence the occurrence or nonoccurrence of different fish of economic value.

In the second place, the problem of the nutrient salts (phosphates, nitrates, silicates), will be taken in hand. Special attention will be paid to the, if any, eventual existing limiting factors for plankton development in tropical seas. So far as our experience goes abundance of diatoms is only found in water masses with a relatively high phosphate content. Thus far never a peak in the diatom population was ascertained when the phosphate content was low as can be the case in temperate waters.

It seems possible, therefore, that there is a limiting factor (or limiting factors) which determine the plankton growth as a whole, which means also that the problem of the productivity of the tropical seas and the problem of the nutrient salt cycle will have to be attacked from another point of view than in colder waters. Next to the question of the distribution of the salinities and nutrient salts the distribution of the fish will be studied in close co-operation with the results of the former investigations.

Special care will be paid to the problem of the river mouths, where very peculiar biological conditions are found and where a special estuarine fish fauna exists which is typical for South-east Asia. A similar fish fauna, though composed of different species, is found in the estuaries of South New Guinea.

Since the last congress in 1939 the following research was carried on in the Java Sea by the Laboratory for Investigation of the Sea at Batavia :—

1. A HYDROGRAPHIC SURVEY OF THE JAVA SEA AND ADJACENT STRAITS

Four regular cruises, taking samples from the surface to the bottom, were made—viz., in the months of January, April, July, and October every year. Besides this work regular sampling was done at the surface by shipping lines and lighthouses. The total amount of water samples collected totalled up to about ten thousand a year. Only salinities and temperatures were determined.

In general it can be said that the current-system changes twice a year under the influence of the monsoons, which are the predominating winds here, the long axis of the almost rectangular Java Sea lying parallel to the direction of the monsoons. During the east monsoon water flows into the Java Sea from the Flores Sea and the Straits of Macassar and leaves it again through the Straits of Sunda into the Indian Ocean and through the channels between Sumatra and Borneo into the South China Sea. In the west monsoon the direction of the currents are just the reverse, whereas the general salinity is one to two promille lower than in the east monsoon.

This changing currents system, together with the varying salinities, have a strong influence on the fisheries for *Decapterus*.

Now and then oceanic water through the Straits of Sunda is pouring into the Java Sea in contrast with the general current system of the east monsoon. This upsets this system for the south-western part of the Java Sea and in accordance with this the general ordinary pattern of the fisheries.

No publications were ready at the outbreak of the war.

2. A SURVEY OF THE BOTTOM FAUNA

This was done especially in the Bay of Batavia. Some interesting facts were discovered. The bulk of the bottom species consisted of molluscs. All specimens were very small, a shell of 1 centimetre was a large one. This bottom fauna proved to be totally different from the molluscan fauna generally found on the shore, which therefore must live in a very limited zone.

The number of species, as always in the tropics is large. One station produced 190 species (not individuals !) per square metre. The amount of living matter, however, which can serve as fish food for bottom dwellers was very low, a fact which is not encouraging for the development of a trawl fisheries in a European style.

In accordance with this the number of flat fishes (not the number of species) is smaller than f.i. in the North Sea and the individuals are small, too, 10–15 cm. being the average, some species and some localities excepted.

3. The River-mouth Problem

The estuaries of the tropics, or at any rate those of South-east Asia, show peculiarities which are not found in colder climates.

In front of each river mouth a horse-shoe shaped bar exists not consisting of sand, but of very soft mud. In this bar no channels are found as would be the case, for instance, in European rivers. This soft, muddy bar is maintaining itself, notwithstanding the fact that heavy tidal streams, sometimes up to 5–6 nautical miles an hour, flow over it twice a day. This bar ends abruptly and very steeply to the landward and has a very gentle slope to the seaward. The result is a peculiar distribution of the salinities, water of high salinity, flowing over the bar at high tide as a kind of submarine waterfall, is captured behind the bar at low tide, and remains more or less stagnant on the bottom of the river proper. These rivers, coming from a very flat and marshy country, have a very slow fall, and the sea-water (more or less diluted) is often found tens of kilometres inland.

In these waters a peculiar and very special fish fauna is found, consisting of species (and even genera) spending their life cycle in these waters with varying salinities. This fauna does not live elsewhere.

The number of species is, for a tropical community, low, the number of individuals very large, probably due to the high amount of plankton in these fertile waters. The plankton growth is much more abundant than in the open sea.

I am sorry to say that all notes and collections are lost.

List of English Publications Since Jan. 1, 1939

Dam, L. van : Estimation of Chlorides in 1 c.c. Sea Water Samples by Means of Syringe Pipettes. *Treubia*, deel 17/5, 1940.

Delsman, H. C. : Preliminary Plankton Investigations in the Java Sea. *Treubia*, deel 17/2, 1939.

Hardenberg, J. D. F. : Some New or Rare Fishes of the Indo-Australian Archipelago : VII. *Treubia*, deel 17/2, 1939.

—— —— Fishes of New Guinea. *Treubia*, Vol. 18/2, 1941.

———— Development of Marine Fisheries. *Royal Asiatic Society of Bengal. Science*, Vol. XII/2, 1947.

———— Some New or Rare Fishes of the Indo-Australian Archipelago : VIII. *Treubia* Vol. 19/3, September, 1948.

Jong, J. K. de : A Preliminary Investigation of the Spawning Habits of Some Fishes of the Java Sea. *Treubia*, deel 17/4, 1940.

AN OUTLINE OF THE WORK OF THE OCEANOGRAPHIC INSTITUTE OF INDO-CHINA from 1939 to 1948

By R. Serene, Oceanographic Institute of Indo-China

At the Fifth Pacific Science Congress a *résumé* was presented of the work of the Oceanographic Institute of Indo-China during the period 1929–1933 ; at the Sixth Congress a *résumé* of that carried out between 1934 and 1939. The period 1939–1948 is that of the war, the unfortunate effects of which are still being felt.

M. Chevey, the Director, died in 1942 ; from 1943 to 1946 the laboratory was closed, and even during the period from July, 1945, to April, 1946, entirely abandoned and given over to pillagers. In April, 1946, M. Serene assumed responsibility for the place, but found neither staff nor equipment ; the task of reconstruction and re-equipment absorbed all his efforts until the end of 1947. In January, 1948, M. Marchad, a new appointee, took up his duties, followed in May of that year by M. Durand, a former member of the staff and in December, 1948, another new assistant, M. Deroux, arrived. In March, 1949, the new Director, M. Drach, will assume his functions. The scientific personnel consists of : M. Drach, Director, M. Serene, Assistant Director, in charge of the crustacean laboratory ; M. Durand, Assistant, in charge of the fish laboratory ; M. Deroux, Assistant, in charge of the plankton and coelenterate laboratory ; M. Marchad, in charge of the mollusc laboratory.

Professor Drach, Professor in the Sciences Faculty of the University of Paris, proposes to direct this team of biologists in the work of coordinating the littoral ecology, and, by means of self-contained diving equipment of the Cousteau type, to extend their researches beyond the area revealed by the spring tides, as far as a depth of 6 metres. This new technique should make it possible to prepare a table showing the various biological facies of the Indo-Chinese littoral zone, which will be a new contribution to our knowledge of tropical coastal waters.

Physical Oceanography

Until 1942 work continued without notable modification according to the general plan set out in 1936. For want of equipment and personnel this work has not so far been resumed ; it is to recommence on 1st March, 1949. In 1950 a new assistant specializing in physical oceanography, who is at present finishing his studies, will considerably widen the scope of this branch of the laboratory activity.

Hydrology

During the period 1939–1942 these operations were confined to measurements of temperature and salinity. Several thousand observations were made, both from a fixed point not far from the laboratory and during the cruises of the laboratory trawler " De Lanessan " and other vessels. The results have been published in the Reports of the Oceanographic Institute of Indo-China. A paper entitled " On Annual Variations in Temperature and Saline Content of Surface Sea-water at a Fixed Point on the Annam Coast," which briefly summarizes some of these observations, was presented at the Congress of the International Association of Physical Oceanography at Oslo in August, 1948.

During this period, owing to the lack of any vessel, the hydrological gradients which formerly were prepared twice a year along the full length of the Annam coast-line, have had to be discontinued. A single cruise of the " De Lanessan " in 1939 made it possible to prepare a Saigon-Batavia gradient. These hydrological gradients give a great deal of information on coastal currents around Indo-China. Current movements as affecting navigation, the biology of marine species, and fishing are all considered. No work has been done as yet on the utilizing of warm waters. The laboratory has not yet a vessel adequate to undertake these researches. No doubt by the end of 1949 one will be available.

At the present time fixed points have been selected, convenient to the laboratory, for the study of the variations in the rhythm of hydrological gradients, particularly in order to study ascending currents at the edge of the continental shelf and the distribution in coastal waters of the fresh and brackish water brought down by the Nhatrang River.

In collaboration with the study of fauna and biogeography outlined below, physical oceanography studies will be completed by pH measurements, estimation of dissolved oxygen, &c., and in general by a more detailed analysis of the various physical and chemical factors of sea-water. In the same way the study of the sea-bottom will not be confined to taking samples of the material of the sea-bottom, but will include systematic study of the samples ; classification of sands by granulometry, pH of muds, and so on.

Study of the Sea–bottom

Up to the present the numerous samples taken for study of sedimentation and of the characteristics of the sea-bottom apart from the collection of samples of fauna have not all been fully used. Although some of the material has already been assembled, the preparation of a chart showing the nature of the sea-bottom in the coastal zone of Indo-China is a task still to be undertaken. A chart already published of trawling bottoms has given some useful information for the fishing industry. Co-ordination of this work, which is at present in progress, will make it possible to draw up a new working programme showing the gaps to be filled, particularly as regards improving our knowledge of fishing bottoms.

In a related field observations are to be resumed of the under-water relief of the coast-line (study of the submarine valley of Mekong, and study of the old continental relationship between Indo-China and the Netherlands Indies). Also soundings are to be taken at certain points at present very little known (such soundings have previously enabled corrections to be made to charts of the Spartly Archipelago).

Biological Oceanography

Continuing the plankton fishing by day and by night which has been regularly undertaken since 1936, nearly one thousand takings of plankton were made between 1939 and 1942. The general results of sorting are now in course of publication. The collections thus made have not yet all been studied. Some, however, have already formed the subject of publications, and Professor Fage's study on Cumacea illustrates their interest. (A paper for presentation to the Congress gives a deeper insight into the working of this section of the laboratory.)

Faunal Studies

One of the principal activities of the Oceanographic Institute of Indo-China is the preparation of an inventory of the marine fauna of Indo-China by the establishment of collections. These suffered a great deal at the hands of pillagers during the war period. The establishment of a museum for the systematic classification of these collections is now in progress. So far, the collection of fishes made by Drs. Chevey and Durand has been reconstructed ; it contains over nine hundred species (about four thousand specimens).

The collection of Coelenterata has not yet been resumed, but those consisting of molluscs and crustacea have been considerably enlarged : more than ten thousand specimens are listed, belonging to about eight hundred different species. It would be premature to make any general estimate of the value of these collections. The study of a group of Crustacea (the Stomatopods) which is the subject of a paper before this Congress is, however, indicative of their interest.

FISHING TECHNOLOGY

In addition to an aquarium and museum open to the public the Oceanographic Institute of Indo-China has an office dealing with information relating to fishing, in connection with the studies of a technological laboratory.

This office, established in 1938, assumed during the period 1940–1945 so great an importance, owing to the economic situation, that from 1943 to 1945 it engaged all the activities of the laboratory, which lost all scientific character. Resuming its proper role, it is particularly concerned with the study of fishing problems, in relation to the biology of seasonal migrating species (increase in production), and to those techniques which may bring about better utilization of the products of the fishing industry. It plays the part of technical adviser to the various Governments associated in the Indo-China Union on maritime fishing questions.

OCEANOGRAPHY OF JAPAN SINCE 1939

By KOJI HIDAKA, Tokyo

INTRODUCTION

ACTIVITIES of physical oceanography in Japan were largely curtailed by the World War II, especially at the close of the Pacific theatre. It can be said, therefore, that the ten years from the Sixth Pacific Science Congress to the Seventh is the period in which we made little progress in this branch of science. A summary of the official and personal activities in various institutions and agencies is now reviewed.

ACTIVITIES IN THE HYDROGRAPHIC OFFICE, TOKYO

In the Hydrographic Office, Tokyo, 103 hydrographic expeditions have been carried out from 1939 up to present in the Kuroshio region, Oyashio area, Equatorial Pacific, Yellow Sea, East China Sea, South China Sea, Okhotsk Sea, Bering Sea, Japan Sea, and other areas. Observations of tidal currents for periods of thirty days have been made at more than ten stations in bays and the Inland Sea. Temporary tidal observations were also made at nine coastal stations. After the end of the war this office was directed by Dr. Kwanji Suda,, a physical oceanographer. The surveying vessels now in use are M.S. " Kaiyo No. 4," " Kaiyo No. 5," and " Tenkai No. 1."

In 1940, Dr. S. Kishindo discussed the deep-sea temperatures and abyssal water movement in the Pacific Ocean, using the deep-sea observations of the " Komahashi," which he directed as captain, and of other surveying ships. He made a vertical section of the Pacific, showing the distribution of temperature, salinity and oxygen, extending from the Bering Sea to the Antarctic Continent, use being made of all the available data of " Carnegie," " Dana," and " Discovery II," as well as of the Japanese surveying ships for the southern hemisphere.

In the same year S. Kuwahara published a table of corrections on the density of sea-water for the sonic depths. He also reported on sonic sounding in 1943.

Dr. Koji Fukutomi has long been engaged in hydrographic observations, constructing in 1945 diagrams for facilitating the use of non-protected deep-sea reversing thermometers, and made in the same year the determination of pressure coefficients of this type of thermometer by a specially devised apparatus. He afterward got a new post in the Hokkaido University and is now working there as a professor.

Kaoru Yamashita has made some important contributions to the reduction of hydrographic data, constructing in 1945 diagrams for computing specific volume and dynamic elements.

In 1947 M. Nakamiya discussed the hydrographic conditions in the Tsusima Current. He is now an able oceanographer and has many contributions to the hydrography of the adjacent seas of this country. Recently he was engaged in the study of the isolated cold water off the south coast of Japan.

ACTIVITIES IN THE GOVERNMENT FISHERIES EXPERIMENTAL STATION

The Government Fisheries Experimental Station, Tokyo, has long contributed to the hydrographic surveys chiefly with the surveying ship "Soyo Maru." The marine research of this organization is now mainly directed by Dr. Kinosuke Kimura, a physical oceanographer.

In 1939 M. Uda and T. Yamashita made a series of experiments on the accuracy of density measurement by means of an Akanuma's hydrometer, which is sometimes used in Japan in place of chlorine titration. They showed that the accuracy is not good enough, but use is made when the chlorine titration is not available for some economic reasons. In 1940 Uda described in detail the hydrographic abnormality in the Kuroshio region off the south coasts of this country, and discussed the nature and behaviour of the isolated cold water, and K. Kimura studied the hydrography in Suruga Bay, a little to the south-west of Tokyo. This year Y. Yamamura devised an optical apparatus for determining the colour of the sea. M. Igarashi examined the variation of the surface salinity due to the rainfall in Kominato Bay, at the northern part of Honshu.

In 1941 Uda discussed the hydrography in the East China Sea in detail.

In 1942 K. Kimura published an intensive investigation on the phenomenon of the Kuroshio water mass frequently approaching towards the coasts. This phenomenon was shown to occur everywhere on the coasts washed by this ocean current with cycles of a half month, one month, and two months, and is considered to depend on the minor fluctuations of this gigantic river in the ocean.

During the period from 1943 to 1944 very few contributions were made to physical oceanography in the branch of fisheries.

In 1945 Kimura examined the results of drift-bottle experiments formerly carried out in Japan Sea and interpreted the current system of this sea.

After the end of the war the activities fell for a while, but rose rapidly in 1947. In the Government Fisheries Experimental Station, now directed by S. M. Tauti, K. Kimura pointed out the abnormally cold water along the Pacific coast in Boso Peninsula, to the east of Tokyo, and studied the results of drift bottle experiments carried out in that summer in Japan Sea. He also described an interesting movement of drift bottles and current drags set adrift in Suruga Bay, showing a counter-clockwise circulation in the bay induced by the Kuroshio water mass. He also determined the current system in this bay from the drift of set-nets.

In 1947 K. Kimura made an interpretation of the formation of isolated cold-water masses to the southern coasts of this country.

Yasukazu Saito, a young research member working with Kimura, also determined the movement of water in the Tsusima Current from the result of drift-bottle experiments. He also published a theoretical research on the wind currents in limited seas, and the oscillations of lake water induced by winds. I. Yamanaka, working also with Kimura, published a report on the remarkable fluctuations of water temperature in Toyama Bay in the autumnal season.

In the Government Fisheries Institute, Professor M. Okada published some remarks on the use of isopycnal charts for calculating ocean currents. He also published a method of determining the currents in the sea, using the principle of continuity of water volume, salinity, and other properties of sea-water. He was an eminent theoretical investigator on the dynamical oceanography, but unfortunately Okada died in 1941 at the age of thirty-nine years.

ACTIVITIES IN THE KOBE MARINE OBSERVATORY

Since the Kobe Marine Observatory was established nearly thirty years ago, and has long tradition and numerous contributions to the science of the sea, it appears to the compiler natural to describe its activities separately from those of the other agencies subordinate to the Director of the Central Meteorological Observatory.

The practical studies on ocean waves have been made by Koji Hidaka, Z. Yasui, and collaborators from 1937 on, the results being published from time to time. In 1939 Hidaka published the results of study of ocean waves and swells by the stereophotogrammetric survey, using a pair of cameras specially mounted on 6-metre base-line. The survey was made at several parts of the Pacific Ocean in the past four years. He deduced some empirical formulas with respect to the relations between winds and waves from the result of this survey.

In 1939 K. Koenuma published his extensive studies on the Kuroshio, the Japan Current, chiefly consisting of water mass analysis and discussion of the hydrography of this current. This paper was afterwards succeeded by a series of important papers on the hydrography of the western North Pacific.

In 1939 K. Hidaka discussed how to select the layers of observations in hydrographical surveys, and showed that the number of layers of observation must be increased in depths shallower than 100 m. This year he proposed a method of calculating the absolute velocity in dynamical calculation given by Bjerknes, use being made of the continuity of water volume and of salinity.

In 1941 Z. Yasui computed the annual variation of water temperature and density along the coasts of Japan, and computed the amplitudes and phases for them.

In March, 1942, K. Hidaka left the Kobe Marine Observatory and was transferred to the Tokyo University as a professor of Physical Oceanography. The then Director Horiguti also left this observatory, and Dr. M. Uda was transferred from the Government Fisheries Experimental Station as a new Director.

Y. Matsudaira discussed in the same year the influence of hydrographic conditions of the North Pacific upon the climate of Japan and tried the long-range forecasting. In the same year Yukimasa Saito published a short note on the tidal currents in the Fukuoka Bay.

In 1943 Uda discussed the accuracy of the oceanographical observations in this country. He also discussed the fusion of icebergs rather theoretically. Yasui examined the annual rise and fall of the sea-level in the Inland Sea derived from the variation of density. He also made several investigations on the scales of ocean waves and winds over the sea. In the same year Uda and H. Arakawa discussed the relation between hydrographic conditions and movement of depressions near Japan.

In the fall of 1943 Uda was called for military service, and Dr. T. Sano succeeded him as the Director. Sano, who was a meteorologist, made little contribution to oceanography. He died prior to taking up his duties in March, 1945, and Yasuo Matsudaira succeeded to the directorship.

In 1944 Z. Yasui published two papers on the tidal currents and the manœuvring of ships. In the same year Yukimasa Saito published an important paper on the calculation of vertical stability in the sea from the dynamical consideration starting from Lagrangian equations. The results of computation are practically unaltered, but the process is much simpler than the older one. He also published a theory of evaporation from the surface of the sea, and that of the stability oscillations of water in the sea.

Recently Saito completed an extensive theoretical research on Oyashio, or the Kurile Current, partly consisting of water mass anaylsis, He also solved the differential equation giving the simultaneous effect of both horizontal and vertical mixing and showed that at a great distance from the sources the horizontal mixing could be neglected.

T. Itiye, who, too, works in this observatory, is also a very eminent young hydrodynamician, completed a new theory of tsunami waves in 1948. He attributes the tsunami to a non-stationary disturbance.

Itiye also showed that when a solitary wave propagating through a uniform channel passes by a narrower part it is divided into a train of waves.

ACTIVITIES OF THE CENTRAL METEOROLOGICAL OBSERVATORY AND MARINE OBSERVATORIES

The Marine Section of the Central Meteorological Observatory was opened in 1942, the first chief being K. Tsukada, who was afterwards succeeded in 1944 by K. Hidaka, Professor of Physical Oceanography of the Tokyo University. He has been a concurrent member since he was transferred from Kobe in 1942.

Prior to this period we have some contributions in this Observatory. In 1941 M. Hayakawa, of the Osaka Meteorological Observatory, published a series of results of model experiments on tsunami and ocean waves. In 1942 H. Arakawa, of the Central Meteorological Observatory, discussed the short-period irregularities observed in the water temperature in lakes and seas, ascribing their origin to the stability oscillations of water layers as suggested by T. Hesselberg some ten years before.

In 1942 a marine observatory was established in Hakodate, Hokkaido, in addition to the Kobe Marine Observatory, whose activities were already described. The first director was Dr. Mashito Nakano, who was afterwards transferred to the Central Meteorological Observatory, Tokyo, in 1947.

As soon as Nakano arrived at his new post in Hakodate he planned the oceanic researches of the Tsugaru Straits between Japan Proper and Hokkaido, Volcanic Bay, and so forth, nearly all these plans having been realized up to the present. He also collected information on sea ice in the Okhotsk and adjacent sea with some results.

As soon as the war came to an end two more marine observatories were added, one being installed in Nagasaki under the directorship of Dr. M. Uda, and the other at Maizuru, on the Japan sea coast, under the directorship of Dr. D. Nishimura. Thus there are in all five marine organizations belonging to the Central Meteorological Observatory.

At the end of 1943 the investigation on the relationship between the propagation of acoustic waves through sea-water and the hydrographic conditions was carried out by the members of the Central Meteorological Observatory, Tokyo. The experiments were carried out in Enoura Bay, near Numazu, and in lakes, with some reasonable results. Afterwards the field-work was chiefly carried out by Y. Takenouti, who constructed the distribution maps of acoustic audibility in the adjacent seas of Japan. The Kobe Marine Observatory also took part in this work, Y. Matsudaira and Yukimasa Saito being the chief personnel engaged in the practical work.

The surf prediction was also studied in the Central Meteorological Observatory, on the principle that surfs depend upon the winds and coastal configuration, the observations being carried out in several coasts from 1943 on, mainly near Tokyo. The results were, however, not complete before the end of the war. The observations were made by the members of the Marine Section of the Observatory, the results being studied by Y. Takenouti, N. Watanabe, and other collaborators.

Y. Miyake in 1944 published an investigation on the bubbles of sea-water, showing that the salinity increases the stability of bubbles—that is, bubbles are apt to persist in a salter water than in a fresher. He now directs a tiny marine station at Jogashima Island, at the mouth of the Tokyo Bay, chemical oceanography being the main contribution.

Mashito Nakano, who was in the Central Meteorological Observatory, Tokyo, published in 1939 a research on the secondary undulations of tides caused by cyclonic storms. He also explained the short-period sea-level fluctuations (one to three minutes) as a sort of swell emitted from the centres of these depressions. He published a monograph on tidal prediction in 1940.

In 1942 he was appointed the Director of the newly built Hakodate Marine Observatory.

Nakano has long been engaged in an intensive research on the effect of prevailing winds upon the depth of bays. This investigation is still continued, the seventh report having appeared in 1947. This year he was called back to Tokyo and worked at the Marine Section of the Central Meteorological Observatory in charge of tidal and oceanic researches.

In the same year he also published a remark on the paper of J. Goldberg on the computation of free oscillations in bays.

In 1948 Hidaka resigned from the chief of the Marine Section, and M. Nakano succeeded his post. Hidaka is now a General Advisor to the Central Meteorological Observatory. Y. Takenouti, formerly working in the Marine Section of the Central Meteorological Observatory, succeeded M. Nakano and became the Director of the Hakodate Marine Observatory in 1947. He, too, is an able oceanographer and now engaged in the exploration of the sea in the northern part of this country. He has many contributions to the penetration of light through the sea-water, and derived the extinction coefficients for the water in the adjacent seas and lakes of Japan.

S. Seki has long been engaged in tidal researches, and published the harmonic tidal constants at many ports along the coast of this country, computed by Tidal Institute method devised by Dr. A. T. Doodson.

N. Watanabe was long engaged in the hydrographic surveys in the Marine Section of the Central Meteorological Observatory, and has written several comments on the observations of surfs and waves. J. Sugiura, M. Koizumi, and J. Fukuoka, of the same agency are young observers engaged in the hydrographic work.

Dr. M. Uda, who has long engaged in a series of hydrographic researches, was on active service during the war. He came back in the fall of 1945, and is now the director of the Nagasaki Marine Observatory.

In 1947 he published a paper on the damage by ocean waves, especially by swells. His recent main contributions are, however, the hydrographic studies, the hydrographic conditions as the symptoms of weather change, the unusual hydrographic conditions in 1941 and 1942 prevailing over the sea to the east of the coasts, fluctuations of Tsusima Current, turbidity in the adjacent sea of Kyushu, and the discussion of the hydrography of the East China Sea, being the chief work appearing in this year. He has also been engaged in the studies of the Kuroshio, or the Japan Current, and related current system in the western Japan. His theory of the isolated cold water off the southern coasts of Japan should be especially noted.

His observatory is now very active and publishes synoptic charts of the adjacent seas of Kyushu and south-western part of the Japan Sea, the harbour charts and many useful pamphlets for navigation, fisheries, and others. It has a surveying ship of about 100 tons and a small motor-boat. Oceanographic surveys in the sea adjacent to Kyushu are now being made actively.

At the Maizuru Marine Observatory the study in physical oceanography is not active now. It has a surveying ship about 100 tons, and a small motor-boat. M. Miyazaki, a young physical oceanographer, published a method of locating the motionless layer in the ocean. The validity of his procedure is not necessarily universally acceptable at present ; still a very hopeful future development is expected.

ACTIVITIES IN THE KYOTO UNIVERSITY

The activities in the Kyoto Imperial University is remarkable in these ten years. T. Nomitsu and T. Takegami in 1939 made a series of researches concerning the deep-sea deposits. They examined the influence of salts dissolved in sea-water upon the precipitation of small particles suspended, and explained the strip-like multiple-layer suspension of mud particles. In the same year Nomitsu and G. Okamoto examined the condition under which the oscillation of water can occur on a shelf, and Nomitsu and K. Seno made a series of experiments on the formation of black cosmic dusts found in deep-sea deposits, and showed that such spherules can be formed by dropping fused metal balls into the water. This year Nomitsu and T. Matsuzaki published an investigation of the abnormally high sea-level accompanying the Muroto Typhoon in September, 1934. G. Okamoto made a theoretical research on the river tides. A very interesting work of Nomitsu in this year is, however, that of the effect of mid-ocean pressure disturbance on the coastal hydrographical conditions. He and T. Hattori explained the abnormal fluctuations of water temperature and salinity in the Osaki Bay as the effects of disturbances propagated from the centre of cyclones or typhoons far to the south, thus enabling us to forecast the approach of the storm in some measure. Nomitsu also studied the relation between the hydrographic conditions and the run-off of the submarine hot springs in the Beppu Bay.

In the next year, 1940, no appreciable activity is seen from Kyoto.

In 1941 Nomitsu and S. Otsuka examined the heavy water in the sea and showed that this can be used as an identifying property between different water masses. Momitsu also published a paper dealing with the polytropic atmosphere and ocean, the coefficient of eddy viscosity differing in different directions. By this supposition he could show that the angle between the steady wind and steady drift currents induced by the former is less than 45°, a result which V. W. Ekman got for an isotropic ocean. He also studied along with Yasukazu Saito the phenomena of freezing of sea water theoretically.

In 1942 G. Okamoto discussed the drift currents in a polytropic ocean considered by Nomitsu in the preceding year. Nomitsu, Yasukasu Saito, and H. Tamura made experiments on the possible formation of sand-banks on the bottom, as the effect of stationary water movement such as secondary undulations of oceanic tides. They also gave some suggestions on the formation of sand ripples.

A very wide gap lies from 1942 to 1945 in which we see scarcely any activity in Kyoto.

In 1945, K. Seno published a consideration on the water movement on the bottom of the Pacific, and through the Bosphorus and Dardanelles Straits.

Very unfortunately Professor T. Nomitsu, who has been very active and guided the researches of younger scientists in his university, died in 1946 on account of an accident. He was sixty-two years of age. We hereby express our deep mourning for his death and pay respect to his great achievement in every branch of geophysics. S. Hayami, a former research member in the Shanghai Institute for the Natural Researches, succeeded to his position. Recently Hayami, with T. Takegami, made some theoretical studies on the turbulence and convection in the uppermost layers of the ocean.

M. Ishibashi, Professor of Kyoto University, has much interest in chemistry of sea-water and has many contributions in this domain of oceanography.

ACTIVITIES IN THE TOKYO UNIVERSITY

In 1942 Koji Hidaka, who has been working at Kobe for sixteen years, was appointed the professor of the Tokyo Imperial University and has given ever since the lectures on physical oceanography in the faculties of science.

In 1943 Hidaka gave a theoretical investigation on the motion of water in an enclosed sea rotating with the earth, showing that an external force can produce the same motion from the surface down to the bottom. Similar attempt was tried in case of wind currents in a viscous water, but T. Itiye showed the solution is not possible.

In 1943 Hidaka showed that the stream lines in the two-dimensional wind circulation in a lake can be compared to the buckling of elastic plates built in along the portion corresponding to the bottom, while a movement is applied on the remaining straight portion corresponding to the wind-driven surface of a lake. This theory was satisfactorily proved by later experiments with steel plates.

In 1944 Hidaka published his results of calculation on the development of surface slope and currents in an enclosed sea induced by winds, use being made of a pair of simultaneous integral equations of Volterra type.

In 1945 Hidaka tried to use the non-protected reversing thermometer for shallower seas and lakes. For this purpose it was necessary to construct a thermometer with pressure coefficient about ten times as large as those hitherto used. S. Watanabe actually constructed this. The observations were made in Tokyo Bay with some results.

In nearly the same year R. Takahashi, of the Earthquake Research Institute, Tokyo University, published a series of important theoretical investigations on the destructive sea waves, or tsunami. He studied the nature of oscillations responsible for the possible sources assumed on the bottom of the sea. In 1948 he discussed the occurrence of tsunami waves by a travelling disturbance on the floor of the ocean.

In 1945 Hidaka devised a method of integrating the differential equations of drift current, being based on Y. Takahashi's idea. This method can be applied to the case of wind stress varying with time.

He examined the method of location of motionless layer in the sea and concluded in 1946 that the motionless layer corresponds to the depth where the second vertical space gradient of salinity vanishes. Afterward M. Miyazaki in 1946 derived a similar conclusion together with the method of location of these layers.

Hidaka is now studying a qualitative analysis of tides in which he hopes to separate the influences of sun, moon, and meteorological effects distinctly, analysis being made on the tide heights as the functions of the hour angles and distances to the earth of the sun and moon. This seems unsuitable to the prediction, because the mechanical operation appears to be very difficult.

In 1947 Hidaka and S. Hikozaka applied J. Proudman's theory of diffraction of tidal waves to the distribution of 1946 tsunami height along the coast of Kauai Island, Hawaii, which is approximately circular in form.

Kozo Yoshida has been showing activities from 1944 on in the practical study of ocean waves and surfs as well as the theoretical investigations of long and surface waves, notably his investigation on the reflection and other related behaviours of long waves at a discontinuity in the section of a canal. He is now engaged in the theoretical proof of Borgën's formula.

K. Kajiura made some investigations on the hydrography of Okhotsk Sea in 1948. Hidaka and T. Suzuki are planning the stereophotogrammetric study of surfs and breakers. They, too, examined the secular fluctuations of the Tsushima Currents from those of the inclinations of thermocline.

ACTIVITIES IN OTHER UNIVERSITIES AND COLLEGES

In 1940 N. Inoue, who was then teaching in the Hakodate Fisheries College, discussed the short-period temperature oscillations observed in coastal waters.

In 1941 N. Obara, of the Tokyo Bunrika University, published a paper on the course of flow of river water poured into Shimoda Bay, a little to the south-west of Tokyo.

Hikoji Yamada, of the Kyushu University, has long been engaged in the theoretical researches of wind-driven water accumulated along the coast. He derived in 1945 several important results which will contribute greatly to the future investigations of allied phenomena.

Koji Fukutomi, Professor of Hokkaido University, published in 1947 a series of original papers on the formation and behaviour of sea ice.

M. Hatanaka, of the Onagawa Marine Chemical Laboratory, belonging to the Tohoku University, Sendai, examined in 1947 the secular variations of the water temperature along our coasts, use being made of about forty years of coastal temperature observations. He concluded that there is a distinct cycle of about eleven years, probably corresponding to the cycle of solar activity.

The Tohoku University has a Marine Biological Station at Asamushi, near Aomori. Dr. Seiji Kobubo in this station is an able marine biological oceanographer, making hydrographic surveys in the Aomori Bay several times a year and publishing the results in a monthly pamphlet with the assistance of T. Kawamura.

PRESENT STATUS OF THE OCEANIC OBSERVATIONS AND RESEARCHES IN JAPAN

The hydrographic observations in our adjacent seas are now being carried out very frequently, under the control of the U.S. Occupational Forces, with the surveying ships of the Hydrographic Office, Central Meteorological Observatory, including four marine observatories and the Government Fisheries Experimental Station, and the local agencies subordinate to them. The elements observed range almost in every branch of physical, chemical, biological, and geological oceanography. Activities, largely suppressed during the war, are now showing rapid recovery. Still the facilities and apparatus are so inadequate that the observations are mostly confined to the layers shallower than 1,000 to 1,500 m. It is very urgent that the equipment should be improved so as to make it possible to make observations in all layers from the surface down to the bottom.

Research in oceanography is being carried on in the Tokyo, Kyoto, and Hokkaido Universities, and the Government Fisheries Institute has several research members, too.

Fixed point observations were also commenced in the fall of 1947, and some hydrographic observations are being made at a fixed station 39° N., 153° E. and on the way to and from this point, this being carried out by the request of U.S. Forces for the protection of air ways. The administration for these observations is made in the Central Meteorological Observatory, use being made of four ships for this purpose.

These government agencies meet in conferences several times every year, the representative members showing each other the results of the observations and expeditions carried out, and discussing the areas to be explored by different agencies in subsequent expeditions.

STANDARD SEA-WATER

Towards 1940 the standard sea-water furnished by Professor Knudsen became very scarce in this country, while its importation was limited by government policy. It was therefore very difficult to carry out further salinity determination, and some alternative proved necessary. For this reason a committee met in the National Research Council of Japan for preparing standard sea-water in this country. The first meeting was held in November, 1940, in Tokyo, and the programme of preparing the standard sea-water was decided. The procedure was twofold. The secondary standard was prepared from the natural sea-water. The primary standard or Urnormal is the sea-water whose chlorinity is determined with reference to the atomic weight silver, so the preparation of atomic weight silver was a first consideration. The preparation of pure silver was referred to Professor M. Ishibashi, but it has not been prepared as yet.

The sampling of sea-water was made at the point 25° 00′ N. 143° 40′ E., about 100 miles south of Titizima Island, Bonin Group. The sea-water taken was increased in concentration by heating so as to have nearly the same salinity as that of Professor Knudsen—that is, about 19·4 per mille. As to the details about the subsequent processes, we have the report of Dr. Y. Miyake, the chemical oceanographer then in charge of preparation. The second sampling was made after the outbreak of the war in 1943, the third after the end of the war in 1947, the sampling being, of course, made near the coasts of Japanese Islands.

As is very natural the standard sea-water must be a universally accepted one, since the oceanography can be promoted only by an international co-operation and data obtained must be of international standard for the accurate determination of salinity in the adjacent seas of this country depends upon whether our standard is accepted as reliable or not. For this reason, a comparison of our standard with those of Copenhagen and of Woods Hole is an urgent matter now, and in an assembly of leading Japanese oceanographers in June, 1948, K. Kimura and K. Hidaka suggested that several ampuras of our standard should be sent to America and be tested there for comparison. Dr. T. Yamamoto, the chief of the committee on the preparation of standard sea-water, made some titrations of our standard, using the standard sea-water of Copenhagen and of Woods Hole, kindly furnished recently by American oceanographers by the courtesy of the U.S. Hydrographic Office, Tokyo Branch. He made an oral report then on the result of titration that the agreement was satisfactory, the value of chlorinity of our standard coinciding with those of Copenhagen and Woods Hole to within 0·01 per mille. For the exploration of the Pacific in future there must not be discrepancies in the determination of chlorinity between America and Japan, It is, the compiler believes, very important for us to pay attention to this point for the future exploration of the Pacific oceanography.

At present the leading chemists engaged in the preparation of standard sea-water are, besides Yamamoto, Y. Miyake and K. Tanii, K. Suda, K. Kimura, and K. Hidaka, who is greatly interested in this work.

DEEP-SEA REVERSING THERMOMETER

Imported deep-sea reversing thermometers of Richter-Wiese make also became very scarce in this country towards the outbreak of the war, Shichiro Watabe, however, a very skilled thermometer maker, made thousands of them for the hydrographic survey of this country. He can prepare both protected and non-protected at present. Of course, the performance is not so good as those of Richter-Wiese, or of Negretti-Zambra. An encouragement by enthusiastic oceanographers, both home and abroad, will improve the function. Watabe remarked to the compiler that Dr. T. G. Thompson, of Seattle, was much interested in his deep-sea thermometers.

At present K. Hidaka is planning a non-protected thermometer for shallow waters. For this purpose, the pressure coefficient must be magnified several times that of the present model. He hopes this kind of thermometer may be tried in foreign countries.

THE OCEANOGRAPHICAL SOCIETY OF JAPAN

This scientific society was established in January, 1941, with Dr. T. Okada as the President. It has issued a popular monthly magazine *Kaiyo no Kagaku (Science of the Sea)* and *Journal of the Oceanographical Society of Japan* (quarterly purely scientific journal), both in Japanese language. Both were suspended by the war after 1944, but we are now preparing for active publication in the future. Dr. Okada resigned this year, and K. Hidaka is now president.

A committee on oceanographic research was established in 1943 in the Japan Society of Promotion of Scientific Research for the purpose of scientific exploration of the sea. It consisted of about 30 leading physical, chemical, and geological oceanographers but was disbanded in 1946 for economical reasons.

ANTARCTIC OBSERVATIONS

The Japanese Antarctic whaling cruises were resumed for the winters 1946–47 and 1947–48, and specialists were allowed to take part in these expeditions for scientific investigations.

During the cruise of the winter 1946–47, T. Shimomura, of the Central Meteorological Observatory took part in the expedition, and obtained oceanographic data, although the results are not yet published.

On the second cruise of the winter 1947–48 Dr. T. Tamura, professor of the Hakodate Fisheries College and the concurrent member of the Hakodate Marine Observatory, and J. Sugiura, a young physical oceanographer of the Central Meteorological Observatory, pushed into the Antarctic circle on board a whaler, as far as 75° 41′ S. and got many oceanic data from the layers down to 400 m., the measurements being made of the water temperatures, salinity, hydrogen-ion concentration, oxygen, silicates, phosphates, colour of the sea, and transparency. Meteorological and biological data were taken, too.

Bibliography

(1) Uda, M. and Imamura, K. (1938): *Hydrographic Bulletin*, No. 17.

(2) Tayama, R. (1939): Terraces of the South Sea Islands Under the Japanese Sea Islands. *Jour. Geol. Soc. Japan*, Vol. 46, No. 549.

(3) ——— (1939): Correlation of the Geological Structure of the South Sea Islands. *Jour. Geol. Soc. Japan*, Vol. 46, No. 549.

(4) ——— (1939): Distribution of Coral-Reefs. *Geogr. Rev. Japan*, Vol. 16, No. 6.

(5) ——— (1939): Coral-Reefs. *Hydrographic Bulletin*, Nos. 10–11.

(6) ——— (1940): Geology, Geomorphology, and Coral Reefs of Truk Islands. *Jubilee Publ. Comm. Prof. H. Yabe, Sixtieth Birthday*, Vol. 1.

(7) Asano, K. (1942): On the Coral Reefs of the South Sea Islands. *Contri. Inst. Geol. Pal., Tohoku Univ.*, in Japanese, No. 39.

(8) Yasuhara, Y. and Uchiumi, R. (1942): Investigations in the Kainan-tô Seas. *Fish. Exp. Sta. of Gov. Gen. of Taiwan (Formosa)*, No. 25.

(9) Yoshimura, S. (1943): Bottom Configuration of the Philippine Islands. *Jour. Ocean. Soc. Japan*, Vol. 3, No. 2.

(10) Ohara, S. (1942): Oceanographic Investigations of the South-western Pacific. *Rep. of East Asiatic Inst.*, No. 307.

(11) Hydrographic Section: Report of Investigations of the Great South Sea Earthquake of 1946 (1948): *Spec. Publ. of Hydrographic Bulletin.*

(12) Hamaguchi, H. (1938): Chemical Investigations of Deep Sea Muds. *Jour. Chemical Soc. Japan*, No. 59.

(13) Shoji, S. (1940): Investigations of the Deep Sea Deposits of South-western North Pacific Ocean. *Jubilee Publ. Com. Prof. H. Yabe, Sixtieth Birthday*, Vol. 2.

(14) Suzuki, K. and Sato, A. (1944): On the Bottom Deposits in the Vicinity of Izu Peninsula. *Jour. Ocean. Soc. Japan*, Vol. 3, No. 2.

(15) Niino, H. (1946): Distribution of Organisms on Banks at the Mouth of Wakasa Bay, Japan Sea and Adjoining Continental Shelf. *Rep. Comm. Marine Ecol.*, Washington, No. 6.

(16) ——— (1943): Distribution of Gravels and Foundation Rocks on the Sea Bottom at the Southern Part of Kamtshatka and the Kurile Islands. *Jour. Ocean. Soc. Japan*, Vol. 2, No. 4.

(17) ——— (1944): On the Bottom Deposits in the Neighbouring Seas of Kamtchatka Peninsula and the Kurile Islands. *Rep. Sci. Invest. North Chishima Is.*, No. 1.

(18) Hada, Y. (1943): On the Foraminiferal Communities and Bottom Deposits of the Java Sea. *Jour. Ocean. Soc. Japan*, Vol. 2, No. 4.

(19) Masui (1943): On the Bottom Communities of Toyko Bay. *Jour. Ocean. Soc. Japan*, Vol. 3, No. 2.

(20) Miyaji, D. (1942): On the Bottom Communities of Nanao Bay. *Jour. Ocean. Soc. Japan*, Vol. 2, No. 1.

(21) Miyaji, D. and Habe, T. (1947): "On Thanatocœnoses" of Bays. *Physiology and Ecology*, Vol. 1, No. 2.

(22) Niino, H. (1938): Bottom Deposits of the Kinshu Bankin Suruga Bay. *Jour. Geol. Soc. Japan*, Vol. 45, No. 540.

(23) ——— (1939): Bottom Deposits of the Yomeguri Bank off the Coast of Noto Peninsula. *Jour. Geol. Soc. Japan*, Vol. 46, No. 550.

(24) ——— (1939): Soundings from Okinoyama Bank, Tokyo Bay. *Jour. Geol. Soc. Japan*, Vol. 46, No. 548.

(25) ——— (1940): The Geology, Topography, and Marine Deposits of Kyurokusima and Its Vicinity. *Jubilee Publ. Comm. Prof. H. Yabe, Sixtieth Birthday*, Vol. 1.

(26) ——— (1943): Soundings from Nakanose Bank, Tokyo Bay. *Rep. Adv. Sci. Soc. Japan*, Vol. 1, No. 3.

(27) ——— (1944): On the Soundings of Oki Banks. *Sigen Kagaku Kenkyujc*, Vol. 1, No. 2.

(28) ——— (1938): Investigations on the Soundings of Drowned Valleys. Part 1: Valley Deposits in the Valley off Toyama Bay. *Jour. Geol. Soc. Japan*, Vol. 45, No. 542.

SYMPOSIUM ON UNDERWATER SOUND AND ITS BIOLOGICAL AND OCEANOGRAPHICAL APPLICATIONS

SOUND AS A TOOL IN MARINE ECOLOGY, FROM DATA ON BIOLOGICAL SOUNDS AND THE DEEP SCATTERING LAYER(¹)

By Martin W. Johnson, Scripps Institution of Oceanography, University of California

[*Abstract*]

Underwater sounds produced by animals or reflected by them can be used in studying concentrations and behaviour of certain marine populations.

Biological Sounds.—Crustacea and fishes are the main sound producers, though whales and porpoises are also capable of making sounds. Crustacean sounds consist mainly of high frequency crackle produced by snapping shrimp. The sound produced by a large population of these shrimp is continuous, and with directional sound equipment their habitats can be detected to distances of 2,000 yards or more.

Studies of the continuity and sound spectrum level of shrimp gives evidence pertaining to stability of populations, their diurnal activities, geographical distribution, and type of bottom and depth of water preferred.

Observations on fish noises have given less useful ecological data. They do, however, demonstrate a regular and pronounced seasonal and diurnal habit of certain Sciaenidæ to form localized choruses, as contrasted with isolated solos by the toadfish (*Opsanus tau*) while guarding its nest or territory.

Reflected Sounds.—The " deep scattering layer " (a sound scattering layer at 150 to 400 fathoms within the sea) was shown by its diurnal vertical migrations to be biological in nature. The partial reflection of fathometer signals in this layer promises to be a useful ecological tool in studying the distribution, concentration, and movements of the organisms involved in causing the scatter.

While using sound as a guide, a preliminary study in 1945 showed a positive correlation with plankton stratification, especially the larger plankters, and the depth of the scattering layer. This relationship may be partly secondary, since the more effective scatterers may be larger forms that subsist upon and migrate more or or less concurrently with the plankton.

Summary of Discussion

Dr. Tweedie inquired whether the mechanism of Cetacean noise production was known, and it was replied that little work had been done. Seals were known to produce an underwater noise sounding similar to that produced by aerial means, though doubtless produced in a different manner. As regards underwater vocal noises, it was observed that a yell is not discernible, but that a sustained humming vibration is able to be picked up.

(¹) 1948, *Journal of Marine Research,* Vol. 7, No. 3, pp. 443–458.

Dr. Hubbs was inclined to attribute whale noises to movement of air back and forward in the lungs, and it was thought possible that they may at times exhale below the surface to produce a noise, although in that case air bubbles would be observed accompanying the exhalation.

Dr. Hiatt remarked that divers can communicate as far as 10 ft. away. It had previously been maintained that "ship worms" could be heard working in the hulls, but Dr. Johnson attributed this actually to Crangon shrimps.

In answer to Dr. Hiatt, who inquired whether the high pitch whale note might be that of a calf. it was doubted whether calves were present with the school of hump-backs. Dr. Hubbs pointed out that it had been determined at Scripps that whales have obviously some means of communication.

Many of these sounds were stated to be within human audible range, such as those of croaking fishes. Others, such as some of the crustacean sounds and the high frequency porpoise sounds, were outside the range of audibility. In fishes, sound is perhaps associated with the breeding cycle, sound-producing organs being confined in some cases to one sex only. Dr. Hubbs indicated that Silurid cat-fishes have stridulating organs on the pectorial spine.

Mr. Powell raised the question of shell-fish noises on New Zealand estuaries. He stated that the clicking noises observed about dusk were perhaps attributable to cockles closing their valves suddenly. Dredgings over estuaries had indicated an absence of snapping shrimp. Dr. Johnson, however, discounted the theory that either oysters or cockles produced the noise, and Mr. Morton stated that on Auckland Harbour estuaries he has found by digging specimens of *Crangon novae-zelandiae* associated with cockles and producing a noise like the fall of hailstones.

Dr. Hiatt inquired whether noises were produced by skin friction in swimming. No work had been done, but Dr. Johnson thought the effects would probably be of minor importance.

Stream lining is well developed in fishes. Tail whipping and muscular movements might, however, produce sound. Dr. Hubbs cited the scarcely perceptible hum of *Leptocottus*, and Dr. Johnson referred to that of grunt-fish and the small alligator fish. There was also cited the clicking sound made by some shore crabs in exuding bubbles from the mouth.

Dr. Emery inquired whether perhaps sea mammals might make use of noises for echo ranging in the pursuit of fish. It was stated also that, on the inverse side, advantage might be taken of artificially produced noises or recordings to frighten away fish from specific localities during T.N.T. depth charge work, during which fish mortality was heavy. It was suggested, further, that fish might be attracted by the reproduction of suitable noises.

Dr. Brunn gave an account of the detection of dolphin schools during the use of high-frequency echo-sounding apparatus. He stated that a school of 100 to 125 were observed smacking the water with their tails with great vigour.

A discussion followed on the occurrence of auditory organs and sound receptors in fish. Dr. Brunn emphasized that fish are able to detect half-tones, as had been established by the production of conditioned reflexes in which a series of auditory effects differing by half-tones had been associated with disagreeable and palatable food substances.

SYMPOSIUM ON SEDIMENTATION AND CHARACTERISTICS OF SEA BOTTOM IN THE PACIFIC BASIN

SEDIMENT DISTRIBUTION ON THE EAST ASIATIC CONTINENTAL SHELVES(¹)

By Francis P. Shepard, Scripps Institution of Oceanography, University of California

[*Abstract*]

During the war charts were prepared for the United States Navy showing the bottom character on the continental shelves along the eastern and south-eastern coasts of Asia. They are based on about four hundred thousand bottom notations from the most detailed Japanese, British, Dutch, and French charts which were available in the files of the Navy Hydrographic Office. The final charts were printed in small numbers by the Hydrographic Office.

The charts show that sediment is distributed irregularly over the Asiatic continental shelves. In few places is there a graduation outward from coarse sediment to fine. Along much of the Asiatic coast mud predominates on the inner shelf, and sand outside. Large rock areas occur, particularly along the Japanese coast where the Kuroshio (Japanese Current) is flowing at a high speed. Rock notations are abundant on submerged hills, off rocky points, in narrow straits, and at the outer edge of the shelves. Mud is found in enclosed bays, and sand is most common in broad open bays, although mud is present in the latter off some large rivers. Sand is the most common type of sediment reported from the Asiatic shelf. The distribution of the sediments is controlled by such factors as (1) sources (large rivers, shore erosion, organic growth, and recent vulcanism), (2) currents (oceanic, tidal, and longshore), (3) waves (on exposed points), (4) bottom topography (submerged hills, basins, and canyons).

Summary of Discussion

Dr. Shepard's results had tended to show that rock notations were encountered most commonly in straits and areas subject to great current sweep, sand on beaches with no large rivers entering, and on continental shelves, and mud in river deposits, inner parts of shelves, and at the heads of submarine canyons.

Mr. Powell, speaking of the results of a ten to fifteen years bottom survey of the Waitemata Harbour and Hauraki Gulf, was able to point to results exactly similar to the conclusions of Dr. Shepard. Coarse sediments were found in the middle of the Auckland Harbour along the tidal current, and fine sediments from soft Tertiary mudstones at the sides. But in the case of the outer islands the normal distribution described in such localities by Dr. Shepard was likewise adhered to. Heavier material is tossed inshore, mud occurring in the deeper portions. It was pointed out by Mr. Powell that the hard bottom sediments in his area were purely

---

(¹) Shepard, F. P.; Emery, K. O.; and Gould, H. R. (1949): *Allan Hancock Foundation Publications, Occ. Pap., No. 9,* pp. 1–64.

organic in origin. There were no gravels, and animal shell remains themselves build up the bottom substratum where the currents are greatest. The tongue of hard bottom deposits extends from the harbour out to North Head. There are also lens-shaped hard areas outside the harbour, amidst the mud, and these again are attributable to increasing current velocities.

Dr. van Baren referred to detailed mapping of the Sunda Sea and the southern part of the China Sea. Sampling of the bottom had revealed, he claimed, hardly any connection between sea movements and bottom material. We might expect the east to west current strongly developed in the Java Sea to affect the distribution of sediments, but no such result was to be found. It was agreed that restudy of the area in light of Dr. Shepard's conclusions would be valuable.

Dr. Shepard asked whether it was not true that there was some amount of coarse material in the Sumatra-Java Strait. It was stated that muddy sediments predominate. Dr. Emery observed also that the sediments are probably not all detrital, which would complicate the matter.

Dr. Kuenen stated that the results tended to confirm that the classical grading with fine sediments outermost does not hold good on the continental shelf. He asked whether waves with a churning action at higher velocity had been considered as well as slower-moving currents. It was answered that this had been thought of, and evidence was cited from California, where detailed work had been carried out on wave effects. The sediments off-shore were very coarse, as the depth was too great for wave action. A programme was under way at Scripps Institute on currents and waves at different depths.

THE WHITE ISLAND TRENCH: A SUBMARINE GRABEN IN THE BAY OF PLENTY, NEW ZEALAND

By C. A. Fleming, New Zealand Geological Survey

An expedition of the New Zealand Department of Scientific and Industrial Research to White Island in January, 1947, stimulated interest in the characters of the sea bottom adjacent to this active volcano. Isobaths drawn on Admiralty Chart No. 2527 revealed a well-defined trench (Fig. 1) extending north-east from the Bay of Plenty coast. The name "White Island Trench" is proposed for this steep walled depression which has a width of about 7 miles, measured from the summits of its walls, and a depth, below the general level of the continental shelf, of about 3,000 ft. The trench can be traced clearly from the 75 fathom isobath to a depth of 850 fathoms at a point 15 miles north-east of White Island. This volcano rises to a height of 1,000 ft. on a ridge which extends seawards from the Rurima Rocks, to delimit the west side of the trench. There is a fall of 5,000 ft. in 5 miles from the top of White Island to the bottom of the trench. Under such conditions in an area of active seismicity, submarine avalanches are likely, and may account for irregularities in the walls of the trench.

Shorewards from the 75 fathom isobath, recent sediments doubtless obscure the trench, but its persistence to the south-south-west is attested by the known structure of the Whakatane district, where Macpherson (1944) has mapped a narrow graben occupied by the deep alluvium of

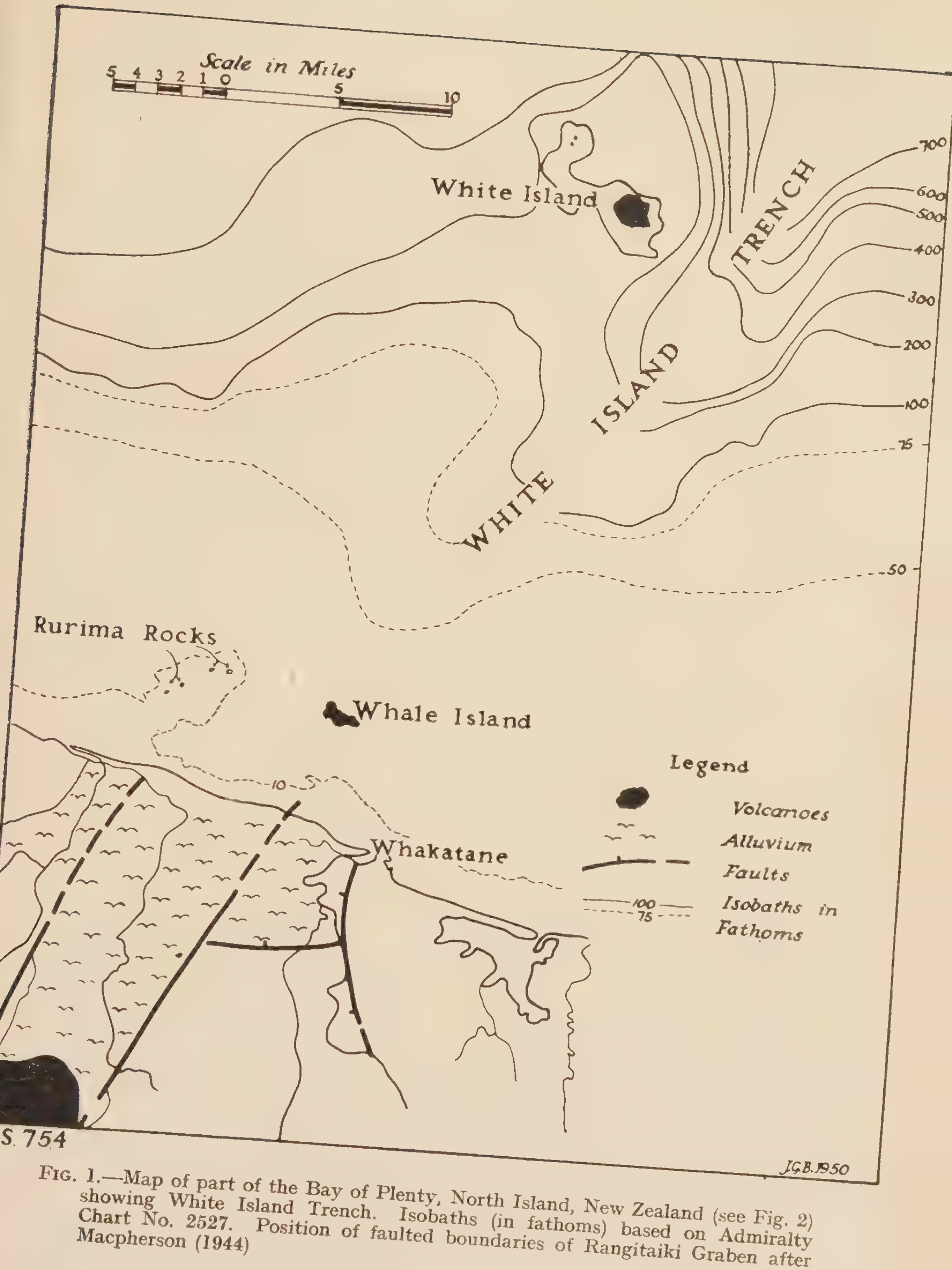

Scale in Miles
5 4 3 2 1 0 5 10
White Island
WHITE ISLAND TRENCH
700
600
500
400
300
200
100
75
50
10
Rurima Rocks
Whale Island
Whakatane
Legend
Volcanoes
Alluvium
Faults
100
75
Isobaths in Fathoms
S.754
JGB.1950

FIG. 1.—Map of part of the Bay of Plenty, North Island, New Zealand (see Fig. 2) showing White Island Trench. Isobaths (in fathoms) based on Admiralty Chart No. 2527. Position of faulted boundaries of Rangitaiki Graben after Macpherson (1944)

the Rangitaiki River, trending inland from Whakatane. Macpherson's boundary faults are shown in Fig. 1. Geophysical work by Modriniak (1945) indicates that sediment fills the graben to a depth of at least 700 ft. It may be safely inferred that the White Island Trench is the seaward continuation of the Whakatane Graben.

Available data do not permit detailed mapping of the sea bottom far beyond White Island. Nevertheless, what soundings there are (Fig. 2) suggest that the White Island trench has considerable extension to the north-north-east towards the Kermadec Islands. The soundings shown in Fig. 2 are too widely spaced to allow determination of the width of the trench over most of its length. The bottom of the trench remains at approximately 3,000 ft. below the adjacent sea-floor, and its greatest known depth below sea-level, 2,050 fathoms, at a point 140 miles south-west of Esperance Rock, constitutes the deepest part of the sea bottom between the East Cape-Kermadec Ridge to the east, and the Gazelle Basin to the west. The low ridge west of the trench suggests a structural " high " which has no precise analogy in the known structure of the Bay of Plenty area.

The relationships between the White Island Trench and other known structural lineaments are fairly obvious. It is parallel to the greater submarine welt and foredeep of the East Cape - Kermadec Ridge and Kermadec-Tonga Trough, and occupies the position of a " back-deep " on the inner side of these folds. It is homologous with the complex volcano-tectonic depression of the North Island of New Zealand to which the name Taupo Graben is applied, and further work will probably show continuity. Still more clear is the relation of the submarine graben to the line of active and dormant volcanoes which Dieffenbach in 1843 recognized as " one connected hearth of volcanic action."

REFERENCES

MACPHERSON, E. O. (1944): *N.Z. Journ. Sci. & Tech.*, Vol. 26, No. 2, (Sec. B), pp. 66-76.

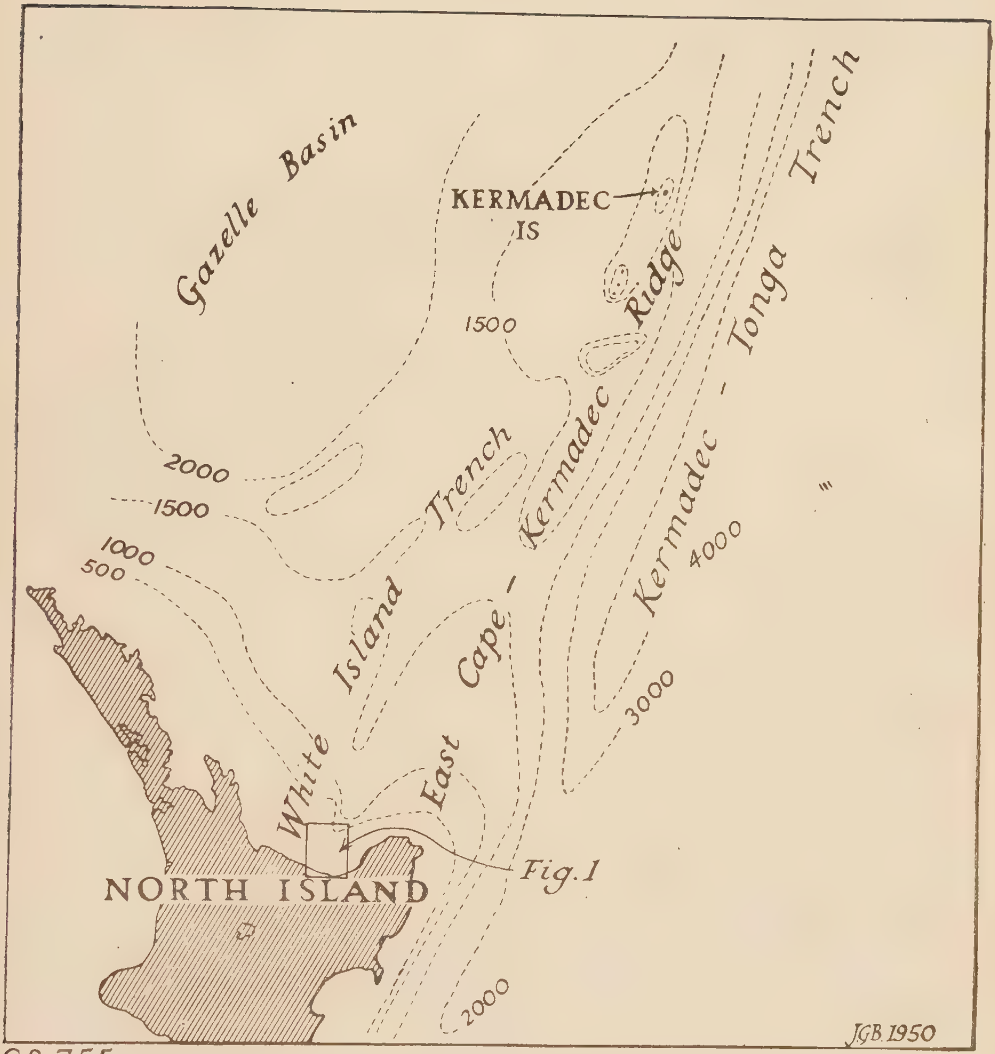
MODRINIAK, N. (1945): *N.Z. Journ. Sci. & Tech.*, Vol. 26, No. 6, (Sec. B.), pp. 327-331.

SUMMARY OF DISCUSSION

Dr. Gutenberg emphasized that such ridges separated by troughs or grabens occurred very widely, and were not an isolated phenomenon. He instanced the island ridges of the East Indies separated by troughs. Other such regions were quite frequent in the Pacific, although their significance was rather obscure.

Mr. Fleming agreed with the last speaker. He pointed out that the White Island trench was a collapse rather than a downfold, but agreed that as such it is by no means unprecedented.

Dr. Kuenen maintained that the present example was important as illustrating a trench actually continuing into the continental shelf as a graben. Dr. Gutenberg considered that a gravity profile across such a ridge and trench would be very valuable, and Mr. Fleming indicated that a gravity meter was to be brought into use, if possible, this year.


Gazelle Basin
KERMADEC IS
1500
2000
1500
1000
500
White Island Trench
East Cape - Kermadec Ridge
Kermadec - Tonga Trench
4000
3000
NORTH ISLAND
Fig. 1
2000
JGB 1950

G.S. 755

Fig. 2.—Generalized bottom topography north-east of North Island, New Zealand. Isobaths based on Admiralty Chart No. 788

SUMMARY OF THE RESEARCHES ON THE SUBMARINE CONFIGURATION AND BOTTOM DEPOSITS OF THE NEIGHBOURING SEAS OF JAPAN DURING 1939–1948

By Hiroshi Niino, Suisan, Koshusho, Japan

A summary of the investigations on the submarine configuration and bottom deposits of the neighbouring seas of Japan during the period covering 1938–1940 is given here. Researches having been carried out extensively along various lines, only the outstanding results are presented.

(1) Submarine Configuration of the Neighbouring Seas of Japan

1. *General Configuration*

A. *Pacific Ocean*

The increase in number of the sounding stations by the echo-sounding method has resulted in the necessity for revision of previous marine charts, and, consequently, a new chart is in the process of publication. Bathymetric charts (No. 6080 and others) of the neighbouring seas of Japan are being published by the Hydrographic Section of the Bureau of Transportation, and at present a new one for the Japanese coasts is now in press. According to this chart, the Japan Trench is narrower than indicated on previous charts, and a depth of 10,600 metres was sounded in it. The Mariana Trench comprises three parts, and the Caroline Oceanic Basin can be divided into two parts in east-to-west direction. The Yap ridge is a prolongation of the Mariana ridge, and the submarine ridge north of Palau continues to the Okino-tori-shima. The bottom configuration of the South Japan Sea (south-east of Shikoku) is complicated, there being many depressions, steep slopes, and, according to the Fisheries Experiment Station, there has been discovered a shallow area measuring 480 metres at 29° 51′ N. lat., 133° 21′ E. long.

Concerning the coral reefs of the former Japanese mandated territory there are numerous reports, and it is now known that the foundations of them consist of the Tertiary or pre-Tertiary formations, whose ages have been determined by paleontological evidence. Among the coral-reefs there exists a peculiar type known as the Table reef.

B.

South China Sea.—Sounding investigations have revealed the existence of a peculiar depression, measuring more than 70 metres in width, between Kainan-to and French Indo-China.

Philippine Seas.—The submarine configuration of the Philippine seas more resembles that of the East India Islands than the neighbouring seas of Japan. Submarine valleys are well developed along the south-eastern coast.

Japan Sea.—According to the results of investigation of the Fisheries Experiment Station of the Hydrographic Section and of Korea, the submarine configuration of the Japan Sea is quite complicated in the southern half and in the central part there is the Yamato Bank (285 m.), North Yamato Bank (418 m.), and north-west of the Oki Islands is the Oki Bank (275 m.). Also, along the Japanese Islands, there exist many ridges.

Okhotsk Sea.—In the northern part of the Okhotsk Sea the continental shelf is 50-100 metres deeper in comparison with other regions. This fact suggests that there must have been a relative change in sea-level.

2. *Special Configuration*

A. *Great Earthquakes and Submarine Configuration*

After the great earthquake of the South Sea at 4.19 a.m., on the 21st December, 1945, the sea area of Kishu and Shikoku was deepened about 1 metre in general. Also large-scale steep slopes were introduced to the submarine configuration in the vicinity of the epicentre.

B. *Submarine Valleys*

There are many submarine valleys along the Japanese coasts. The lower limit of the valleys extend beyond 1,000 metres depth, and the upper limit (shallower) is cut deeply in the continental shelf. Some of the valleys have their upper limit around 120 metres depth, while others are even shallower, sounding only 20 metres depth. The valleys are imbricate, with many branches (tributaries) cut into the continental shelf.

C. *Ridges and Banks*

Many ridges and banks have been found to be distributed near the continental shelf of the Japanese Islands. These ridges and banks are arranged roughly parallel to the coast of the Japan Sea and are provided with steep slopes with rather flat summits which measure only 120–140 metres in depth; these appear like tilted blocks. On the sea bottom are also found volcanic ridges; these are an extension of volcanic ranges on land.

(2) BOTTOM DEPOSITS OF THE NEIGHBOURING SEAS OF JAPAN

1. *Bottom Deposits in General*

A. *Deep Sea Bottom Deposits*

It is interesting to know that an analysis of the deep sea mud collected by the Hydrographic Section proved the presence of radium and calcium.

B. *Bottom Deposits of the Coasts*

Pacific Coast.—A survey of the bottom deposits in the vicinity of the Izu Peninsula shows that the rocks building the adjoining land have direct influence on the bottom deposits. Also a survey of the Wakasa Bay shows similar results, and, furthermore, the relation between the distribution of grain size and oceanic currents has been clarified. It may be said that the bottom deposits of coasts is closely related to crustal movement in the vicinity. Along the coast of Kamtchatka there is exposed a fossil-bearing bed rock at the depth of about 300 metres, and similar phenomenon also exist in the neighbouring seas of Japan down to considerable depths. Off the Kurile Islands are found rather extensive Diatom deposits.

The relation between foraminiferal communites and bottom deposits has been studied in the Java Sea, and the relation between bottom animals and bottom deposits in enclosed bays has been studied in various parts of Japan.

2. *Bottom Deposits of Regions with Special Submarine Configuration*

A. *Bottom Deposits of Ridges and Banks*

There are ridges and banks believed to be a product of tectonic activity, and, leaving aside one case of foundation rocks, the others are built of fossil-bearing Tertiary sediments whose summits are covered with coarse-grained sand formation. Fine sand is distributed around the ridges to considerable depths. There are many such ridges and banks arranged parallel to the coast of the Japan Sea, while on the Pacific coast they have been recognized only at the mouths of the Suruga and Tosa bays.

B. *Bottom Deposits of Submarine Valleys*

The submarine valleys of the Japanese Seas are imbricate in pattern, with steep sides which expose fossiliferous Tertiary formations, and the valley wall of the submarine valley of Shikoku exposes Pleistocene rocks. Gravel and fine sand is distributed on the walls of the submarine valleys, while in the central parts are found muds. Judging from the grade distribution of the sand and mud in the vicinities of submarine valleys it appears that at present the valleys are being gradually filled by the action of oceanic currents.

TRANSPORTATION AND DEPOSITION BY TURBIDITY CURRENTS

By PH. H. KUENEN, Groningen, Holland

[*Abstract*]

Experiments by the author confirmed that water containing a load of sediment will flow under the influence of gravity along the bottom of a body of standing water. The maximum density is 2; with higher concentration the turbid current changes to a slide.

Turbidity currents of high density might be set up on the sea floor by: (*a*) slumping, the material becoming more diluted; (*b*) by a mud-flow on land reaching the coast and continuing along the bottom; (*c*) the waters of a heavily silt-laden river, if heavier than sea-water, might flow along the bottom beyond the mouth; (*d*) by churned up mud initiating a flow, which picked up more sediment and thus increased its density.

A remarkable property of currents of high density is the fantastic power of transportation. With a destiny of 2 individual blocks can be transported 14,000 times as heavy as by a clear current of equal velocity and volume.

It appears likely that the currents might transport great volumes of silt, sand, and even coarser fractions over large distances of submarine slopes. They should continue over basin floors and mount the opposite slope owing to their great momentum, then depositing the coarser fractions. The fine silt and mud would be carried back again to the deeper parts of the basin.

Experiments showed that the deposits tend to be graded from coarse to fine both in a horizontal and vertical direction. It is believed that this mechanism may account for some cases of graded bedding in which coarse fractions are involved, and that are remarkable for the wide expanse over which each bed occurs, resting on undisturbed fine fractions of the preceding bed. Also the emplacement of deep-sea sands far from the original source might be accounted for in this manner.

Dr. Tulley inquired as to the origin in nature of the material postulated in the flows in Dr. Kuenen's experiments. It was answered that the cause might be found in a slump, with the material taking up water to reach a stage where flow is possible. Dr. Shepard stated that this had been proved to occur in the case of mud at the head of a canyon. A process of filling up took place until a state of instability was reached and the semi-fluid material commenced to slide down. Dr. Kuenen further instanced mud-flows on land after floods, or the action of rivers containing sufficient silt to provide a specific gravity approximating to 2. Or, again, sediment might be churned up by waves to produce a mixture of high specific gravity.

Mr. Banwell mentioned the examples of coastal drift on west coast of South Island of New Zealand, causing harbour silting. It had been estimated that about 5,000,000 cubic yards of material were so shifted annually along 150 miles of coast-line. Mr. Gage commented on the absence of erosion of previous sedimentations which was regarded by Dr. Kuenen as characteristic of this mode of deposition. He pointed out to the contrary that erosive effects are frequently encountered in sedimentary sequences of New Zealand Tertiary and pre-Tertiary. Had Dr. Kuenen always found an absence of erosion in graded bedding. And, referring to Mr. Banwell's remarks, why was it found that at times sorting took place, and that at other times characteristically ungraded beds resulted from slumping ?

Dr. Kuenen attributed this variation to differences in the type of mud, slope, particle size, and water admixture, through all gradations from a sliding slump to a true turbidity current. Erosion may in part occur, but is often far from complete. Mr. Gage agreed that in cases where chips have been torn up by erosion the phenomenon was very noticeable, but that the converse case of lack of erosion tended to be less readily noticed.

Dr. Lillie referred to Bailey's views on submarine landslipping. Were turbidity currents regarded as an explanation in these cases ? It was pointed out that Bailey is not clear on this point. Dr. Lillie referred to variations in graded bedding in quarries, often with peculiar effects. There may be coarse to fine grading, interrupted however by lenses of thin bands often less than half a millimetre thick of carbonaceous material. Dr. Kuenen thought these might be attributable to remains of seaweeds and marine plants.

Dr. Shepard spoke of cores in submarine canyons, as in Monterey Bay, showing well graded pebble sequences, with sharp breaks in the cores between the coarse stratum below and the fine above. He instanced many cases where fine material of turbibity currents has been carried considerable distances. Was it possible that the fine material might be carried on when the coarser grades had been precipitated ? Dr. Kuenen inclined to the view that muddy water might get caught between the coarse particles and silt filtered off.

Dr. van Baren objected that the total amount of mud in relation to water in Dr. Kuenen's experimental buckets where S.G. 2 is attained, might far exceed anything occurring in Nature. Could we expect such a density of mud to flow in Nature without dispersion ? Dr. Kuenen held that this depended on the shape of the bottom. Flows emerging from a canyon will disperse, but momentum will carry material a great distance.

Dr. Tulley questioned how the very restricted occurrences of slumping, as, for example, off the Columbia and Fraser Rivers, could give rise to widespread effects. It was pointed out that material may, however, travel long distances with steep gradients as at the bottom of canyons. Dr. Emery mentioned a distance of 70 miles in fresh water with a very low gradient.

Dr. Tulley agreed that in the case of the Fraser Estuary mud might be abnormally quickly precipitated owing to the high salt content of sea-water.

FORMATION OF THE SEA BOTTOM OF THE SUNDA SEA

By Dr. F. A. van Baren, University of Indonesia, Buitenzorg

[*Abstract*]

The Sunda Sea is the large shallow sea comprised of the South China Sea and the Java Sea situated between the Island of Borneo, the peninsula of Malacca, and the Isles of Sumatra and Java. The mineralogical research of bottom samples of the floor of this sea revealed that ten sediment-petrological groups or provinces could be recognized, as listed below, in their standard mineralogical composition.

Standard Compositions

Group.	Opaque.	Transparent Minerals in Mutual Percentages.																			
		Tourmaline.	Zircon.	Garnet.	Rutile.	Anatase.	Brookite.	Titanite.	Staurolite.	Kyanite.	Andalusite.	Sillimanite.	Chloritoid.	Epidote.	Saussurite.	Glaucophane.	Amphibole.	Augite.	Hypersthene.	Topaz.	Picotite.
Krakatau—group ..	31	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	24	31	44	..	..
Y—province ..	46	6	5	..	..	..	..	..	..	..	..	..	..	14	..	..	6	21	48	..	..
Z—province ..	18	4	8	42	4	1	..	..	2	..	1	..	..	20	..	..	3	8	7	..	..
Deli—group ..	1	1	6	1	..	..	..	..	..	..	..	..	..	..	..	..	92	..	..	..	..
Bawean—group ..	2	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	98	1	..	..
Java—group, type I	30	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	33	42	25	..	..
Java—group, type II	5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	5	90	5	..	..
Borneo—group, type I	68	7	4	..	4	..	..	..	3	..	78	..	..	3	..	..	1	..	..	..	..
Borneo—group, type II	76	16	25	1	5	5	..	1	1	..	22	..	..	15	..	..	8	1	..	..	..
Meratus — Plaut — group	60	4	19	..	8	10	..	..	4	..	11	..	..	20	..	3	1	12	3	..	5
Mixed province ..	59	2	9	..	..	..	..	..	3	..	61	..	..	23	..	..	1	..	..	1	..
S. China Sea—group	77	9	29	1	1	1	..	..	1	..	8	..	..	29	..	..	19	1	1	..	..
Malacca—group ..	44	7	22	..	..	..	..	..	..	..	5	..	..	16	2	..	15	1	33	..	..
Banka — Billiton — group	74	24	64	..	4	..	..	..	1	..	1	..	..	1	..	..	3	..	2	..	..

The Krakatau- and Java-group, including Bawean and Deli-group, are volcanic deposits originating from both recent and, especially in the Java group, Tertiary tuffaceous sediments. They cover the southernmost part of the sea-bottom of the Java Sea and of the Straits of Malacca. They are characterized by pyroxenes and/or amphiboles.

The Y and Z provinces in the Krakatau area are of divergent composition. They are stratigraphically older and probably form the core of an anticline on which the coral reefs in the Bay of Batavia and of the Thousands Islands are situated. The Z province may be an old strand-sand, as is concluded from the typical rounded habit of the garnet.

The area of the centre of the Java Sea is held to represent the surface of an old peneplained region, the monadnocks of Banka and Billiton being relicts of the granites occuring in the area of original pre-Tertiary formations.

The northernmost area is comprised of the Borneo, Malacca, and South China Sea associations. The Borneo group is characterized by andalusite (up to 78 per cent.) in the eastern part (I), the amount of epidote increasing towards the west (II). Type I covers the peneplained Banka-Billiton part of the old Sunda continent, II was sedimentated on the northern part consisting of Malacca and South China Sea group.

The Meratus-Plaut group is separated as being derived from the island Pulu Laut and the metamorphic rocks of the Bobaris-Meratus-Mountains of south-east-Borneo.

The Malacca group is distinguished because of the typical ragged features of the hypersthene and of the habit of the hornblende, which makes a close relationship to Scrivenor's " Pahang Volcanic Series " obvious.

SUMMARY OF DISCUSSION

At the request of Mr. Powell, Dr. van Baren proceeded to supplement his address with an indication of the source and nature of each of the bottom materials plotted. Illustrating from maps and charts, he directed attention first to a region north-west of Java, where volcanic influence was marked and the bottom sediments included volcanic glass and other igneous derived material. But some samples from this same region were found to have no relation at all to volcanic areas. One sample from the Bay of Batavia included rounded garnets, appearing like fragments of shore sand, but having no relation to the shore deposits of the present day. This material probably represented a sand deposit of an older period. Hornblende, amphiboles, augite, and hypersthene were cited among the other minerals represented.

The area of the centre of the Java Sea was held to represent the surface of an old peneplained region with granites, and with tin deposits associated. A large mass to the east of Borneo consisted of Tertiary sediments derived from the south seas, which in Tertiary times has come as far as the west of Borneo. Metamorphic materials played a large part in the composition.

Dr. Shepard inquired whether the sediments described could not have been carried out after river cutting ; the sediments might have been carried out from various petrographic provinces so as to cover up the original river deposits. He agreed that sections and cores would be needed for conclusive statements to be made. Dr. Kuenen referred to Pettersson's cores through 5 metres of recent deposits. Dr. Emery inquired as to the occurrence in the area of phosphorite. This had not been encountered in significant proportions, but the occurrence of glauconite was described.

Dr. Kuenen questioned the validity of the Rhine comparison by Dr. Shepard. Material from various provinces might at some depths be covered up by recent deposits but in the Rhine mixed recent material was very widely dispersed by the distributaries of the delta. Dr. van Baren stressed that in all these examples greater depth samples were needed.

SYMPOSIUM ON PHYSICAL AND CHEMICAL PROPERTIES OF PACIFIC OCEAN WATERS

ELECTRICAL AND MAGNETIC EFFECTS OF OCEAN CURRENTS

By G. E. R. Deacon, Admiralty Research Laboratory, England

Summary of Discussion

Dr. Tully inquired as to the manner of hooking up the electrodes used, and also the material of which they were constructed. They were stated to be of silver and silver chloride, protected in glass wool and soldered to the cable. Measurements were made by a flux meter so as not to take too much current from the electrodes. How quantitative could the investigation be made? The potential gradient would have to be correlated directly with some actual measurements. There would be perhaps an inaccuracy of only 10 per cent., which was good in any kind of physical oceanography. An investigation of the earth current had been made in the United States to establish correlation between magnetic disturbance of aurora and earth currents. A very definite correlation does exist, although there was not yet established any field measuring station.

If observations were made in an estuary there might be other tributary channels converging on the main current which greatly complicate the results. Dr. Deacon proceeded to ask himself the question as to whether measurements could be made across a permanent current of great dimensions such as the Gulf Stream. In a section from Florida to Key West there might be a gradient of 3 or 4 volts. Might it not be reasonable to suppose this would have an effect on the deposition of sediments.

Mr. Allen inquired about observations on inland water effects. It was replied that the significance of this problem was appreciated.

Dr. Emery questioned what would be the results in the Strait of Gibraltar where an outward current existed below and an inward at the top. It was replied that a resultant of the two effects would tend to be established. Dr. Emery mentioned the cable from Hawaii to the mainland and raised the point of its bearing upon sedimentation measurements. It was held that tidal streams in the American coastal region would give the predominant effect.

A New Zealand member asked about possible Cook Strait applications of Deacon's work. Tidal currents up to 7 knots were here established, and in the 40 m. from Wellington to Plimmerton there was a 5½ hour tide difference producing consequently a very strong current. There was also the effect of oceanic currents in Cook Strait. Dr. Deacon assured the inquirer that the physics department of any University College could set up the apparatus, though it was agreed that interpretation of data might raise local difficulties.

TIDAL INVESTIGATIONS IN THE PACIFIC

By E. C. McKay, U.S. Coast and Geodetic Survey

Prior to World War II, tidal information for the Pacific Ocean area had been accumulating slowly from various sources for many years, but it required the impetus of war operations to accelerate its correlation and analysis and to emphasize the need for additional and more comprehensive tidal data.

Before the outbreak of hostilities there were certain areas whose tidal characteristics could as a whole be considered as having been adequately determined. Representative of such areas is the Pacific Coast of the United States, where the U.S. Coast and Geodetic Survey has maintained primary tide stations in continuous operation for many years. Along this particular coast tide data are also available for hundreds of intermediate tide stations, occupied primarily as vertical control stations for hydrographic surveys.

To a somewhat lesser degree there may also be included in the regions of generally adequate tidal coverage the Pacific Coast of Alaska, the Hawaiian Islands, and the Philippine Islands. Particularly is this true of south-eastern Alaska. More detailed development of the complicated tidal movements in the Aleutian Islands and Bering Sea areas can be expected from primary tide stations established during the war and from hydrographic operations now actively in progress in these areas. Fortunately, most of the tide records which had accumulated from many years of survey operations in the Philippine Islands had been transferred to the United States before the beginning of hostilities and were immediately available in the files of the U.S. Coast and Geodetic Survey for the detailed analyses to be demanded by war operations.

Until recent years there were long sections of the Pacific Coast of Central and South America for which little observational tide data were available. An opportunity to improve this situation was presented when in 1940 arrangements were completed for a programme of tidal investigations in co-operation with American republics.

In carrying out this project the U.S. Coast and Geodetic Survey, in co-operation with the countries involved, established twelve tide stations at selected localities in the area between Central Mexico and Southern Chile. By 1942, when the installations were completed, there existed a simultaneously operated chain of primary tide stations covering the entire Pacific Coast of the Americas from the Aleutian Islands to Magellan Strait.

The records obtained as the result of this programme have been subjected to detailed analysis, with the result that along this coast, where tidal information was formerly meagre, there are now key locations where the harmonic constants and other tidal characteristics are reliably established. These stations can now serve as control points to which secondary stations may be referred by comparison of simultaneous observations. They also provide more precise data on the types of tide which characterize this area ; information that is necessary for planning to best advantage the location of needed additional stations. It is expected that present and proposed mapping operations by the Inter-American Geodetic Survey and the individual countries will result in a much closer spacing of tide stations for local control purposes with a corresponding increase in tidal knowledge for intermediate coastal areas.

During the war period the U.S. Coast and Geodetic Survey was called upon to assemble tidal information for Pacific Ocean combat areas. This information was prepared in the form of special reports dealing with specific areas and covered the entire Pacific coast-line from Bering Sea to the Dutch Indies, including the island groups west of the Date Line. Since coverage of the areas involved was required to be as complete as possible, every available source of relevant material was consulted and utilized in the processing of these investigations. Not only did these special studies succeed in their primary purpose of developing existing tidal information, but they also provided a complete inventory of available data which would permit of an effective appraisal of the adequacy of existing records and provide the basis for planning the distribution of stations for any future systematic tide surveys.

Plans for such surveys had in fact been in process of formulation while the war in the Pacific was still in progress. Prior to the war the general lack of facilities in this area had imposed serious obstacles to the practicable development of any co-ordinated tidal programme. However, it was anticipated that the many war-created installations, scattered throughout the Pacific in connection with war and occupation activities, could be utilized to good advantage to provide the sites, transportation, and operating personnel essential for the effective prosecution of an integrated tidal programme. A reconnaisance approach to such a programme was initiated by survey units of the armed forces which were under instructions to obtain tide records wherever an opportunity was afforded and a considerable amount of useful data from a number of localities was accumulated from this source.

Following the war, rehabilitation of tidal installations in the Philippine Islands was accomplished at the earliest opportunity and primary tide stations are presently being maintained at Manila, Jolo, Davao, Cebu, Legaspi, and San Fernando. During 1946 tide stations were established on Kwajalein and Eniwetok in the Marshall Islands, on Wake, and at Hilo in the Hawaiian Islands. The first three were originally installed in connection with the Bikini bomb-tests and later for seismic sea-wave investigations.

Early in 1947 the first steps in a systematic tide survey of the Pacific were taken with the installation of tide stations at Koror in the Palaus, Manus in the Admiraltys, Guadalcanal in the Solomons, and at Midway, Johnston, and Palmyra in the Hawaiian area. In late 1947 and continuing through 1948 the programme was expanded by the addition of stations on Okinawa, Guam, Dreger Harbour on New Guinea, Rabaul on New Britain, Bougainville in the Solomons, and on Christmas Island and American Samoa. Records are also being obtained from stations previously established in Apia in Samoa and Truk in the Carolines. Present plans call for the installation at the earliest opportunity of additional stations in Japan and China. Where practicable, stations are to be operated for one or more years.

The initial tide station installations have as their general objective the determination of basic tide data both for immediate local utility and for planning modification and expansion of the programme to adapt it to the long-period needs of the area. Continuous records for a period of a year will provide sufficient data for the evaluation of the harmonic constants and the time, range, and type characteristics for prediction and tide-table purposes. Also from series of this length there can be obtained tidal datum planes necessary for the vertical control and reference of surveying and construction operations.

In the Pacific Ocean area there are known to exist many combinations of tidal types and characteristics of irregular extent and distribution. To chart this distribution by delineating areas of similar or comparable tidal characteristics with more certainty than is possible with existing data is one of the principal problems of the present investigation, and one that will require considerable flexibility in programme development.

As the results from individual stations become available it will be possible to assess the value of each station for continued operation. Some it may be desirable to eliminate after their characteristics have been demonstrated to be essentially similar to those at companion stations, while in some areas of complicated tidal movement the need for additional stations of intermediate location will be apparent. Gradually there should evolve a scheme of station distribution representative of the varying tidal conditions encountered in different areas and suitable for long-period operation.

Continuous records over a period of years are necessary for certain purposes, chief among which are the evaluation of heights and frequency of extreme tides of meteorological or seismic origin, the determination of mean tidal values from short series of observations through comparison with reference stations, and the investigation and correlation of monthly and yearly variations in sea-level.

Meteorological or seismic disturbances occur at irregular intervals and with varying intensity so that a limited period of tide observations cannot be depended upon to give a satisfactory evaluation of their effects on tidal heights. Results from many such disturbances must be recorded before reliable estimates can be made of the heights and frequencies of extreme high and low waters expected under varying conditions.

As the Pacific Ocean regions develop, tide data will be needed for the local projects of many localities. Meeting this expected demand will be greatly facilitated by the availability of a network of primary tide stations for which basic tide data have been predetermined. Through comparison with the primary station or stations of similar characteristics, short series of tide observations involving little effort or expense to obtain will then suffice to produce tide data of acceptable precision for most practical purposes.

For any locality there is a distinquishing seasonal variation in sea-level which is approximately periodic from year to year. The form of this month-to-month variation may be indicated from a single year of observations, but several years of observations are generally required to average out the non-periodic part of the variation. The periodic part of this monthly variation must be reliably established as a prerequisite to determining the harmonic constants of the principal long-period constituents and to correcting tidal datum planes to their mean values.

The cumulative yearly sea-level averages at long-period stations, when referred to fixed datums defined by bench marks, furnish a measure of changes in sea-level relative to land elevations. At any particular station the indicated change may be due to an absolute change in sea-level, an absolute change in land elevation, or to a combination of both. To permit a separation and apportionment of the two movements, long-period tide observations of world-wide distribution are needed for comparative purposes. In view of the extensive world coast-line involved the number and distribution of primary tide stations are presently far from adequate, a situation which it is hoped will ultimately be greatly improved by the programme under discussion.

Any programme of tidal investigations for an area as extensive as the Pacific Ocean must necessarily be in the nature of a continuing project. Its development will depend on many uncertain factors, and many operational difficulties are expected to be encountered. Already some of the original installations have had to be abandoned due to typhoon damage, withdrawal of occupation forces, or inadequate maintenance facilities. Suitable replacements or substitutions for these must be made, and many new stations added to round out the initial stage of the programme. If a reasonable degree of success is to be attained it will be largely through co-operative effort. Various Government agencies, scientific and engineering groups, and local organizations and individuals have already contributed invaluable assistance, and the future progress of the programme must rely to a very large extent on their continuing interest and aid.

DESCRIPTION OF BATHYTHERMOGRAPH WITH WATER SAMPLING APPARATUS

By A. F. Spilhaus, University of Minneapolis

Summary of Discussion

In reply to Dr. Frances Clarke's inquiry as to how deep the apparatus could be used it was stated that the present model is built for 150 fathom work, and the cost, which used to be inordinately high, is now brought down to 700 dollars for the sea sampler and 400 dollars for the bathythermograph. Dr. Clarke was advised to purchase an entire new apparatus rather than to contemplate attaching the sea sampler to an existing bathythermograph.

Dr. Foerster wished to know if the bottles could be enlarged to provide for increased volume samples. This could be done although displacement increases error. The best way to enlarge the bottles would be to lengthen them, though it would be much preferable to set two triggers to operate at the same depth if a double sample were required. The water sampler can actually be used in a stationary position, but it is best worked at a moderately high speed, where a constant lag is attained. If used in a stationary position it is as well to pull up slowly, and error introduced can be easily corrected.

Dr. Spilhaus pointed out in general the simplicity of his method even for use in fishing-boats, after which the titrating could be done ashore and the whole data assembled by relatively untrained workers.

It was asked whether provision could be incorporated for automatic continuous recordings of salinity as the instrument went down. Work was proceeding at Woods Hole along these lines, and perhaps ultimately oxygen and salinity measuring instruments could be incorporated. But the difficulties in letting down an electric cable are great. Dr. Miller wondered whether, by using methods for eliminating the titrating stages, oceanographers might not be providing themselves with a sort of " Frankenstein " for providing data at much greater frequency than could possibly be made use of. Mention was also made of dropping mercury electrodes to give continuous oxygen readings. But, of course, the need for a sampler still remains. We have other needs in oceanographical chemical data besides oxygen and salinity.

Professor Burbidge assumed that most of the work described was at low speeds ; it was pointed out in reply that 20 knots represents a considerable speed for working. The instrument could not well be adapted for greater depths than 150 fathoms, although a crude apparatus reached 1,000 fathoms, necessitating the use of water compressibility as the pressure-gauging device. The accuracy, however, falls off markedly.

A CONTRIBUTION TO THE OCEANOGRAPHY OF THE SULU SEA(¹)

By Herbert W. Graham(²)

Introduction

The Sulu Sea is a " basin " sea surrounded by the Philippine Islands and Borneo located between latitudes 5° N. and 12° N.; longitude 117° E. and 123° E. It is separated from the South China Sea to the west by the elongated Island of Palawan, from the Pacific Ocean to the east by the southern Philippine Islands, and from the Celebes Sea to the south by the Sulu Archipelago.

The Sulu Sea has been visited by a number of oceanographic expeditions, but until the present investigations has never been subjected to intensive study. The " Challenger " occupied two stations in the eastern part of the sea. One " Dana " station was located in the south-east portion. One " Snellius " station was included in the Sulu Sea in the south central portion. The " Rambler " occupied one station in the north-east while the " Penguin " occupied two stations in the eastern part. The " Nassau " and " Albatross " also made temperature observations. Only seven stations with serial temperature observations have been made in the Sulu Sea until the present investigations. Bathythermograph records have been taken in the extreme north-eastern strip of the sea (Leipper and Wood, 1947). Japanese data on Philippine waters recently made available include no stations in the Sulu Sea. Data on the distribution of salinity in the Sulu Sea are very meagre, while information regarding specific chemical substances is even more scanty.

The present report is based on investigations of the Philippine Fishery Programme of the United States Fish and Wildlife Service. As part of this agency's study of Philippine waters an intensive study was made of the Sulu Sea in order to obtain information basic to the investigation of the fishery resources of the Philippine region.

The Sulu Sea was surveyed once during the north-east monsoon and again during the south-west monsoon by four cruises of the " Spencer F. Baird." Each survey was made by occupying a grid of stations spaced 60 miles apart. The first survey during the north-east monsoon was conducted on two cruises—one from 7th to 14th October, 1947, the second from 3rd to 11th December, 1947. The survey during the south-west monsoon included two cruises, also—one from 15th to 25th June, 1948, the other from 10th to 16th July, 1948. Thirty-seven stations were occupied during the first survey and forty-two during the second survey, most of which were reoccupations of previous stations.

Serial temperatures and water samples were taken from the surface to 2,000 metres and at one station to 4,000 metres. In addition to salinity, the water was analysed for dissolved oxygen, phosphate, silicate, hydrogen-ion concentration and, in some cases, nitrate, nitrite, and alkalinity.

(¹) Published with permission of the Director, United States Fish and Wildlife Service.

(²) On leave from Mills College, Oakland, California.

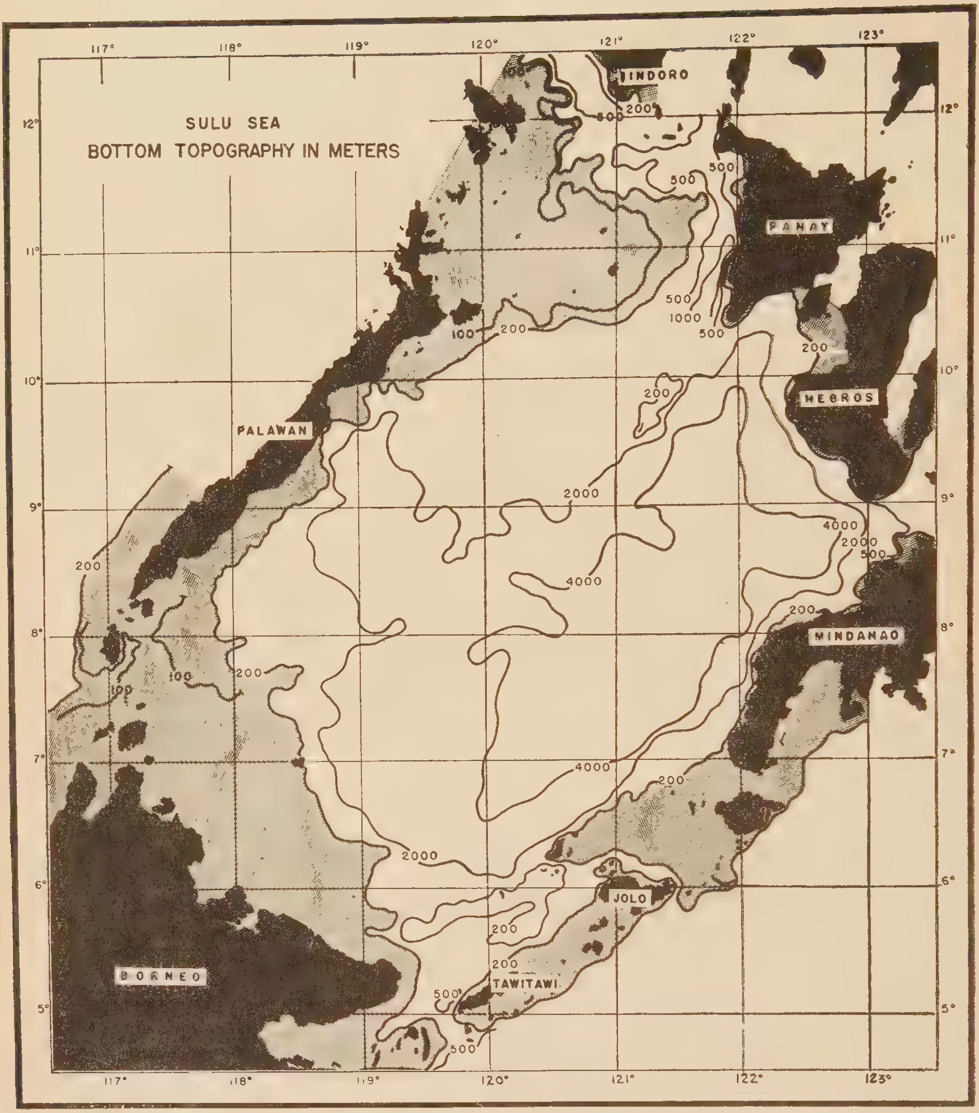

SULU SEA
BOTTOM TOPOGRAPHY IN METERS
117°
118°
119°
120°
121°
122°
123°
12°
11°
10°
9°
8°
7°
6°
5°
MINDORO
PANAY
NEGROS
PALAWAN
MINDANAO
JOLO
TAWITAWI
BORNEO
100
200
500
1000
2000
4000

CHART 1.—Bottom topography of the Sulu Sea

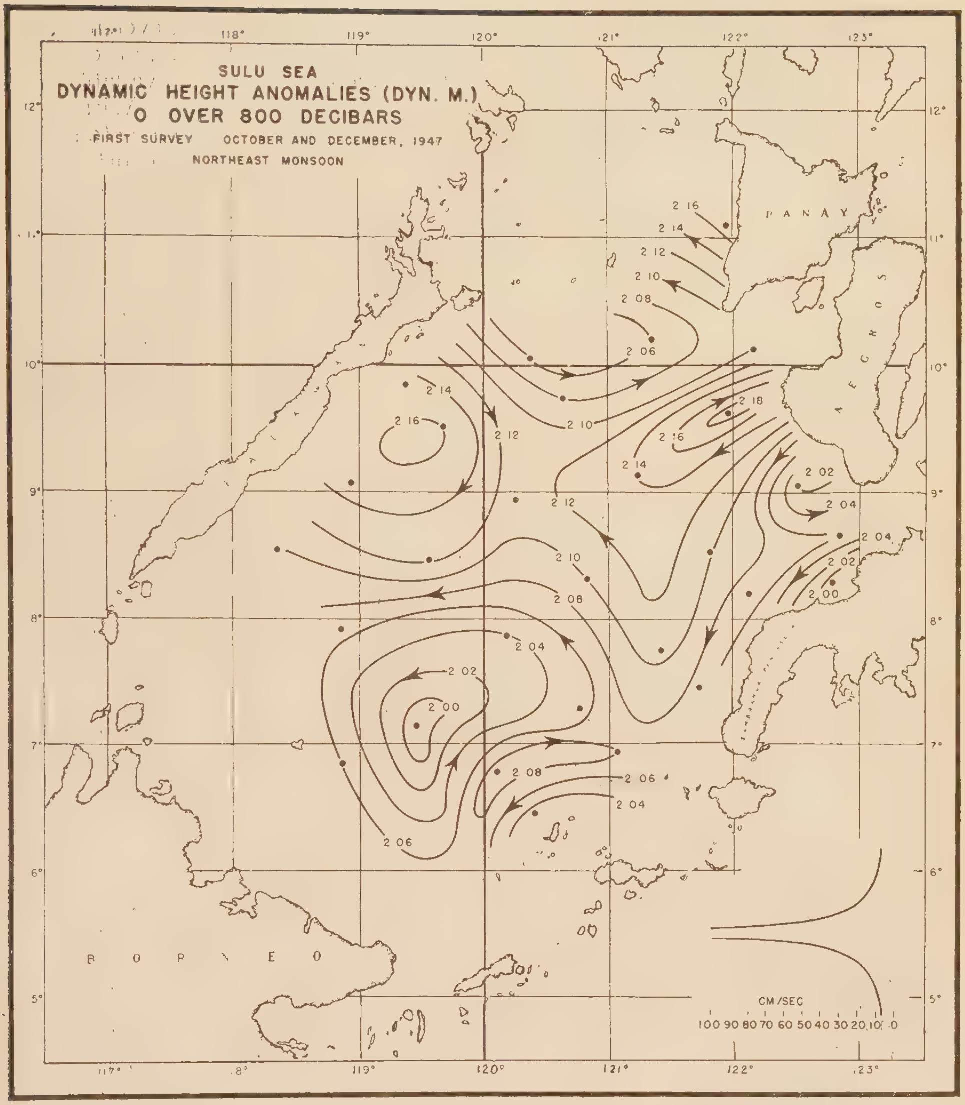

SULU SEA
DYNAMIC HEIGHT ANOMALIES (DYN. M.)
0 OVER 800 DECIBARS
FIRST SURVEY OCTOBER AND DECEMBER, 1947
NORTHEAST MONSOON
118°
119°
120°
121°
122°
123°
12°
11°
10°
9°
8°
7°
6°
5°
PANAY
NEGROS
BORNEO
2 18
2 16
2 14
2 12
2 10
2 08
2 06
2 04
2 02
2 00
CM/SEC
100 90 80 70 60 50 40 30 20 10 0

CHART 2.—Dynamic topography: Dynamic height anomalies for the surface relative to the 800-decibar surface during October and December, 1947

Temperatures were recorded with Watanabe deep-sea reversing thermometers obtained from the Philippine Coast and Geodetic Survey. The calibration certificates for these thermometers were not available so they were calibrated by comparison with two Richter and Wiese thermometers. The certificates for these two reference thermometers also are not available at present. Therefore the temperatures reported here are only relative. The exact absolute values must await the calibration of the reference thermometers. Corrections to be applied will not be of great magnitude, and such corrections are not expected to alter the general picture of the distribution of temperature and density as computed from "Baird" data. A comparison of the "Baird" temperatures with those of the "Snellius" for the deep water of the Sulu Basin show very good agreement. Therefore it seems justifiable to report conditions now even though there are slight errors in the absolute values.

ACKNOWLEDGMENTS

The oceanographic work of the Philippine Fishery Programme was planned and supervised by Herbert E. Warfel under the administration of Hugh W. Terhune. In the planning phase John Lyman and Richard Tibby acted as advisors. The collection of data in the field was under the direction of Joseph Goodman and Ralph Jentoft, while William Wood was in charge of the reduction and analysis of data. Much of the routine computation was made by Teodoro Megia. Alfonso Sebastian and Bonifacio Dionisio also assisted in the computations and graphical presentation of data. Fabian Magpile prepared the finished charts and graphs. The chemical analyses of water samples were made by Mr. Ricardo Lao, Manuel Llorca, and Manuel Ciocon, under the direction of Dr. Goodman and Mr. Jentoft.

THE SULU BASIN

The Sulu Sea has a maximum depth of 5,576 metres, and over a large area is over 4,000 metres deep. Chart 1 shows the outstanding features of the bottom topography. The 4,000-metre and 2,000-metre contours are shown throughout. The stippled area indicates depths of less than 200 metres. The 100-metre and 500-metre contours are drawn only at critical points. The main purpose in presenting this chart is to indicate the nature of the communications which exist between the Sulu Sea and adjacent waters. It is evident that the Sulu Sea is connected with surrounding seas only over shallow sills or through narrow troughs.

The surface waters are in communication with the South China Sea to the west through Balabac Strait, which lies between Palawan and Borneo, and to the north by way of Mindoro Strait west of Mindoro. Communication with the open Pacific is by way of various straits between the southern Philippine Islands to the east and by way of the Celebes Sea to the south through the Sulu Archipelago.

All these communications with outside waters are restricted to upper water layers. The shallowest of the connections is to the east. Although deep water connects the Sulu Sea with the Mindanao Sea (between

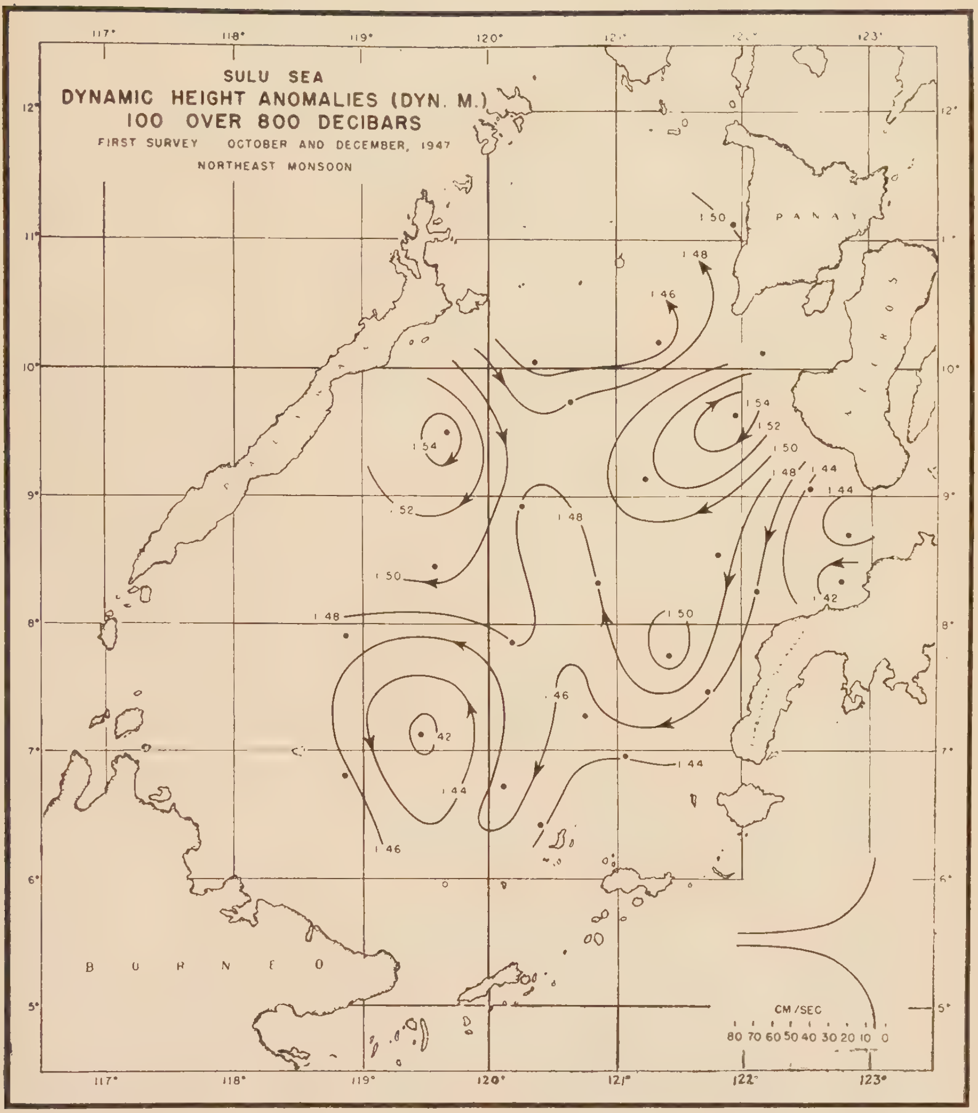

SULU SEA
DYNAMIC HEIGHT ANOMALIES (DYN. M.)
100 OVER 800 DECIBARS
FIRST SURVEY OCTOBER AND DECEMBER, 1947
NORTHEAST MONSOON
117°
118°
119°
120°
121°
122°
123°
12°
11°
10°
9°
8°
7°
6°
5°
PANAY
BORNEO
1.50
1.48
1.46
1.54
1.52
1.50
1.48
1.54
1.52
1.50
1.48
1.44
1.44
1.42
1.50
1.46
1.42
1.44
1.44
1.46
CM/SEC
80 70 60 50 40 30 20 10 0

CHART 3.—Dynamic topography: Dynamic height anomalies for the 100-decibar surface relative to the 800-decibar surface during October and December, 1947

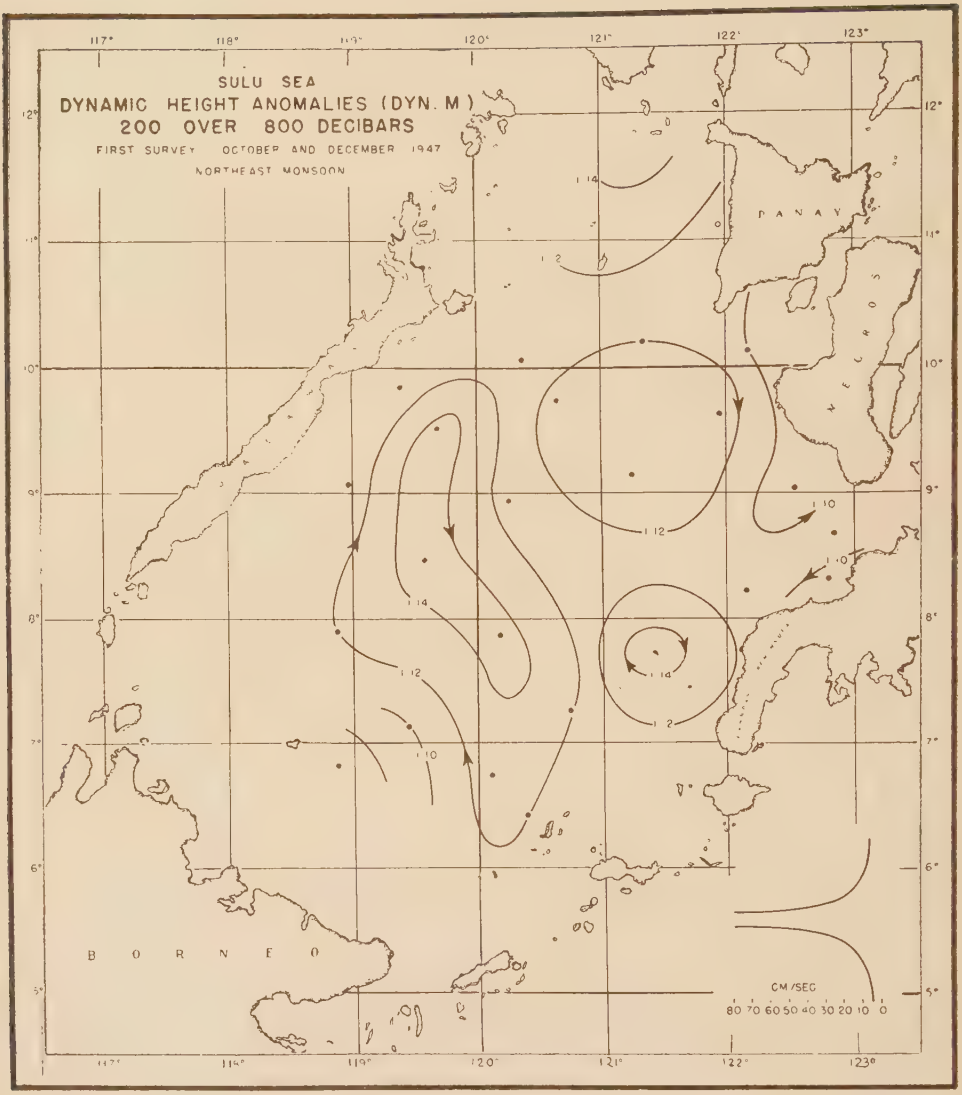

SULU SEA
DYNAMIC HEIGHT ANOMALIES (DYN. M)
200 OVER 800 DECIBARS
FIRST SURVEY OCTOBER AND DECEMBER 1947
NORTHEAST MONSOON
117°
118°
119°
120°
121°
122°
123°
12°
11°
10°
9°
8°
7°
6°
5°
PANAY
NEGROS
BORNEO
1.14
1.12
1.10
CM/SEC
80 70 60 50 40 30 20 10 0

CHART 4.—Dynamic topography: Dynamic height anomalies for the 200-decibar surface relative to the 800-decibar surface during October and December, 1947.

Negros and Mindanao), the Mindanao Sea is isolated from the Pacific below a depth of 64 metres by the reef fringing the east side of the islands. Communication with the Pacific through San Bernardino Strait farther north is equally restricted.

The next deepest connection with outside waters is Balabac Strait. The sill depth here is less than 100 metres. To the south there are two deeper troughs which connect the Sulu Sea with the Celebes Sea. One of these, east of the Island of Jolo, has a sill depth of 225 metres. A deeper one is Sibutu Passage between Tawitawi and Borneo, where the sill depth is about 275 metres.

The deepest connection between the Sulu Sea and outside waters is between the South China Sea to the north by way of Cuyo East Pass west of Panay and Mindoro Strait west of Mindoro. The sill depth here is about 450 metres.

The depth of these sills is of the greatest importance to the understanding of the hydrography of the area.

Wind Direction

The winds in the Sulu Sea are definitely seasonal, although the two monsoons are not so well developed here as in more northern parts of the Philippine waters. This is particularly true of the southern part of the sea (Selga, 1931).

At Cuyo, in the northernmost part of the Sulu Sea, the north-east monsoon extends from October to April, reaching its height from January to March. The south-west monsoon extends from June to September, with greatest development in August. Neither the intensity nor the duration of the south-west winds is as great as the north-east.

At Jolo, in the Sulu Archipelago, the seasons are much less marked. North-easterly winds predominate from December to April, while southerly winds are more common from May to November, but there is a high percentage of calms throughout the year.

Thus the "Baird's" operations in the northern half of the Sulu Sea in October were conducted at the beginning of the north-east monsoon when it might be expected that the surface currents still maintained their pattern of the south-west monsoon period, while the survey in the southern half of the area in December was made after the north-easterly winds had probably had time to establish a pattern more characteristic of the north-east monsoon.

The second survey of the Sulu Sea, in June and July, was conducted in the first half of the south-west monsoon, when one can reasonably expect to find at least a partial development of the current pattern characteristic of that season.

Surface Currents

The islands of the Philippines lying to the east of the Sulu Sea are in the direct path of the North Equatorial Current. Since this is a strong current which persists the year around it can be expected to have a strong influence on the waters to the west throughout the year. As this current strikes the Philippines it is deflected part to the north and

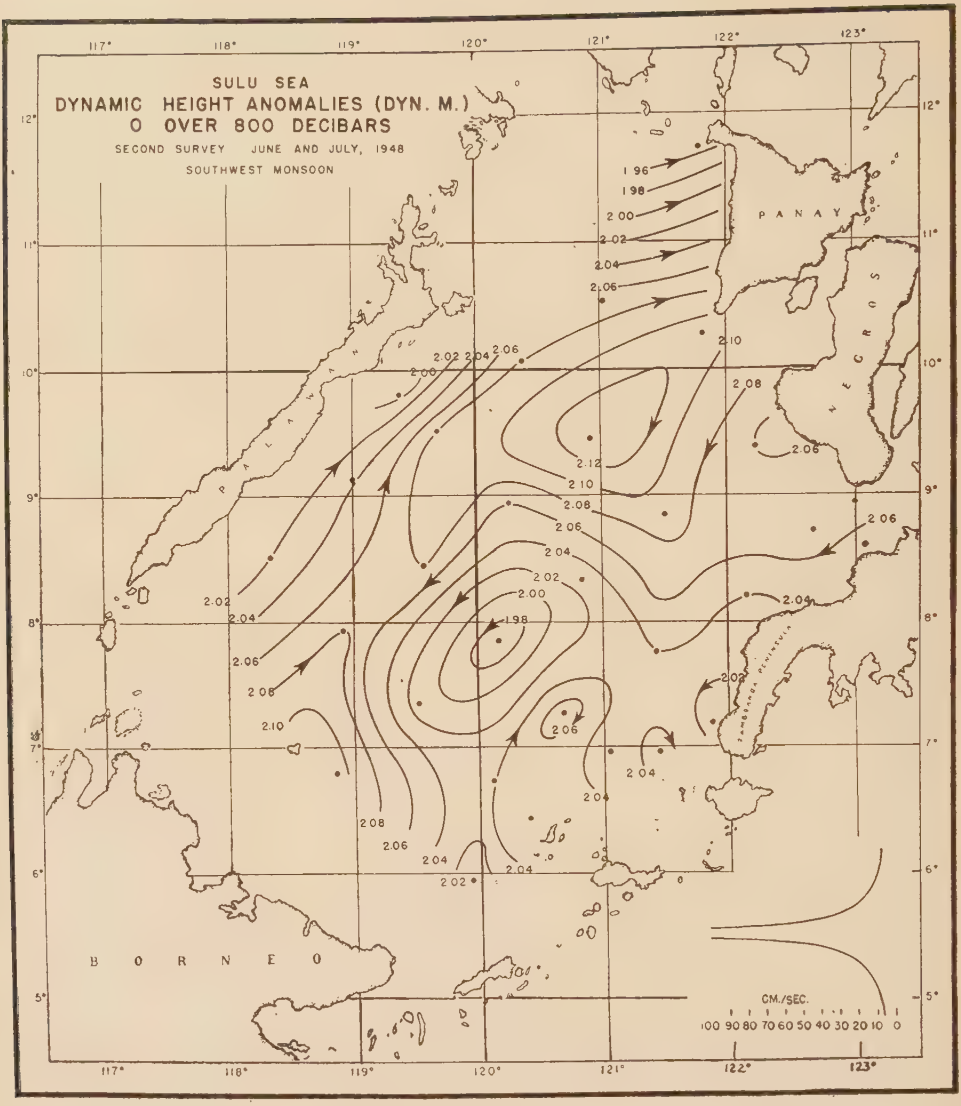

SULU SEA
DYNAMIC HEIGHT ANOMALIES (DYN. M.)
0 OVER 800 DECIBARS
SECOND SURVEY JUNE AND JULY, 1948
SOUTHWEST MONSOON
117°
118°
119°
120°
121°
122°
123°
12°
11°
10°
9°
8°
7°
6°
5°
PANAY
NEGROS
PALAWAN
BORNEO
ZAMBOANGA PENINSULA
1.96
1.98
2.00
2.02
2.04
2.06
2.08
2.10
2.12
CM./SEC.
100 90 80 70 60 50 40 30 20 10 0

CHART 5.—Dynamic topography: Dynamic height anomalies for the surface relative to the 800-decibar surface during June and July, 1948

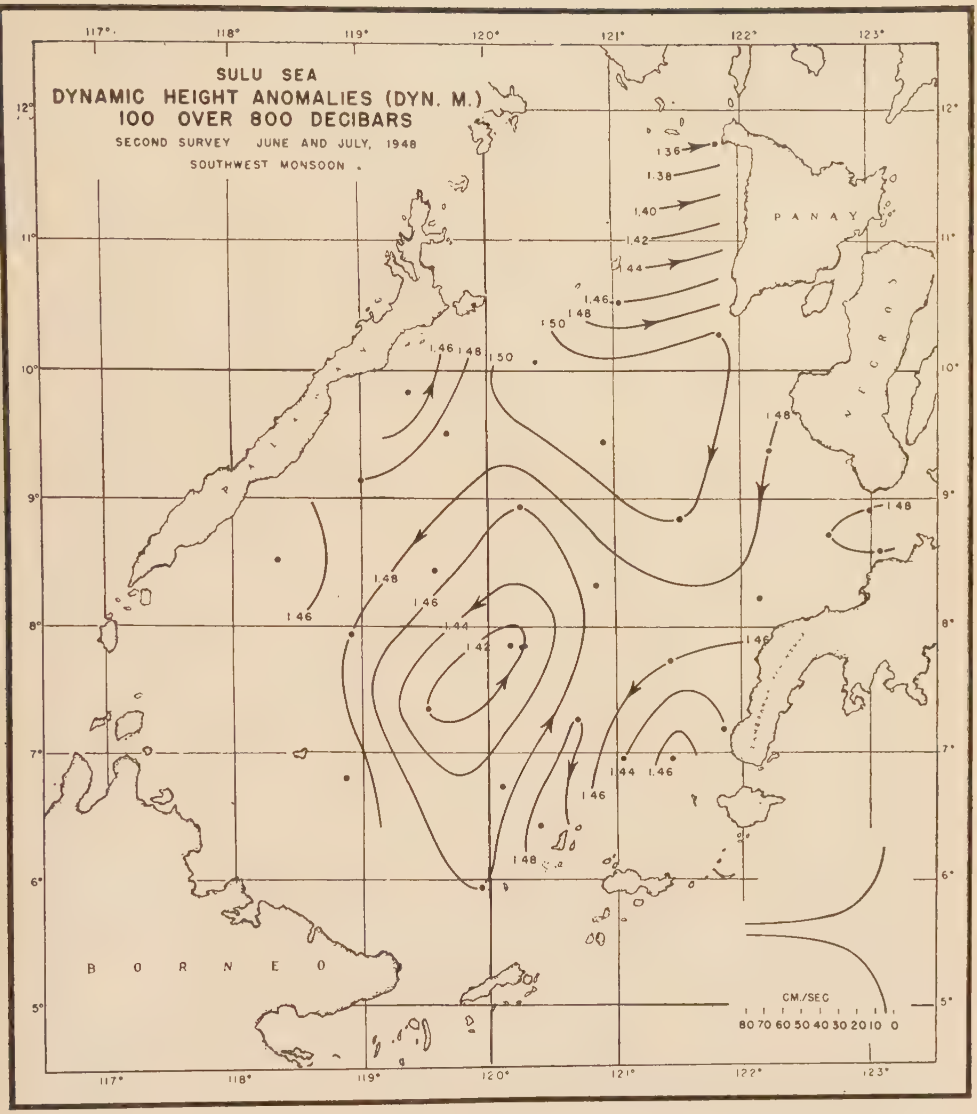

SULU SEA
DYNAMIC HEIGHT ANOMALIES (DYN. M.)
100 OVER 800 DECIBARS
SECOND SURVEY JUNE AND JULY, 1948
SOUTHWEST MONSOON
117°
118°
119°
120°
121°
122°
123°
12°
11°
10°
9°
8°
7°
6°
5°
PANAY
BORNEO
1.36
1.38
1.40
1.42
1.44
1.46
1.48
1.50
1.42
1.44
1.46
1.48
CM./SEC
80 70 60 50 40 30 20 10 0

CHART 6.—Dynamic topography: Dynamic height anomalies for the 100-decibar surface relative to the 800-decibar surface during June and July, 1948 part to the south, while part finds its way through the passes between the islands. North equatorial water from the open sea can find its way into the Sulu Sea by way of Leyte Gulf and the Mindanao Sea to the east, and to a somewhat lesser extent from the north through San Bernardino Straits and Guimaras Strait.

CURRENTS: NORTH-EAST MONSOON

At the Surface (Chart 2).—The dynamic height anomalies of the surface relative to the 800-decibar surface for the first survey are shown in Chart 2. The circulation at that season of the year consisted of a complex set of eddies. Two large eddies dominated the pattern—a cyclonic eddy to the south, which hereafter will be referred to as the "South Central Eddy", and an anticyclonic eddy toward the north-east part of the sea, which hereafter will be referred to as the "North Central Eddy." A number of minor eddies also occurred, an anticyclonic eddy to the north-west, and one south-east of the South Central Eddy; a cyclonic eddy in the extreme north and another to the west.

No strong flow of water to or from the Sulu Sea is indicated. The flow from the Mindanao Sea is limited to the southern part of the area between Negros and Mindanao. This flow turns south. The southern part of this current lies close to the Zamboanga Peninsula and probably eventually enters the Celebes Sea either near Basilan Island or continues along the Sulu Archipelago to enter the Celebes Sea by way of Sibutu Passage east of Borneo. The main stream of water entering from the Mindanao Sea turns northward through the central part of the Sulu Sea and then turns west. In the western part of the Sulu Sea the stations were too shallow for dynamic computations, so the fate of this water beyond longitude 119° east is not shown. It may continue out through Balabac Strait to the China Sea, but at least part of it probably swings south as part of the South Central Eddy, while another part probably turns to the north as part of the North Central Eddy.

Although the two halves of the Sulu Sea were surveyed two months apart during the north-east monsoon there is no difficulty encountered in drawing the dynamic topography for the sea as a whole, so that the pattern presented in Chart 2 probably represents conditions generally characteristic of the beginning of the north-east monsoon.

At 100 Metres (Chart 3).—The dynamic height anomalies of the 100-decibar surface relative to the 800-decibar surface for the north-east monsoon shows a pattern of flow essentially the same as at the surface although the indicated velocities are less. The North Central Eddy and the South Central Eddy are well defined, the circuitous route of the west-flowing current remains as do the two northern eddies.

At 200 Metres (Chart 4).—At a depth of 200 metres the currents are very weak and the pattern of flow is somewhat different from that at higher levels. There is still some evidence of the North Central Eddy. The South Central Eddy has disappeared and is replaced with an extension of the eddy to the north. The small eddy found off the Zamboanga Peninsula at the 100-metre level persists at 200 metres. The 200-decibar surface does not show the westerly current found at higher levels. This may be related to the fact that there is no outlet to the China Sea at this level. Water from the southern side of Mindanao Sea may still flow southward into the Celebes Sea at this level.

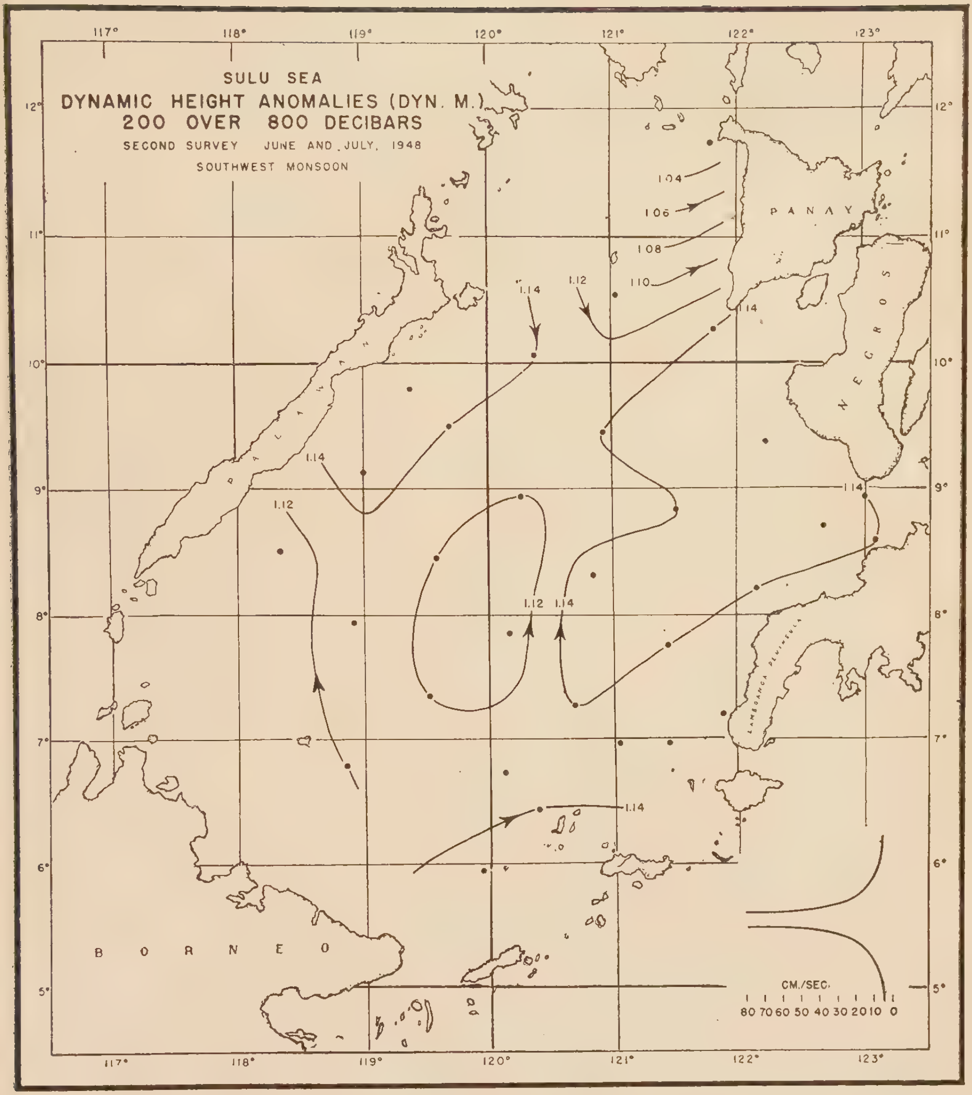

SULU SEA
DYNAMIC HEIGHT ANOMALIES (DYN. M.)
200 OVER 800 DECIBARS
SECOND SURVEY JUNE AND JULY, 1948
SOUTHWEST MONSOON
117°
118°
119°
120°
121°
122°
123°
12°
11°
10°
9°
8°
7°
6°
5°
PALAWAN
PANAY
NEGROS
BORNEO
ZAMBOANGA PENINSULA
1.04
1.06
1.08
1.10
1.12
1.14
CM./SEC.
80 70 60 50 40 30 20 10 0

Chart 7.—Dynamic topography: Dynamic height anomalies for the 200-decibar surface relative to the 800-decibar surface during June and July, 1948

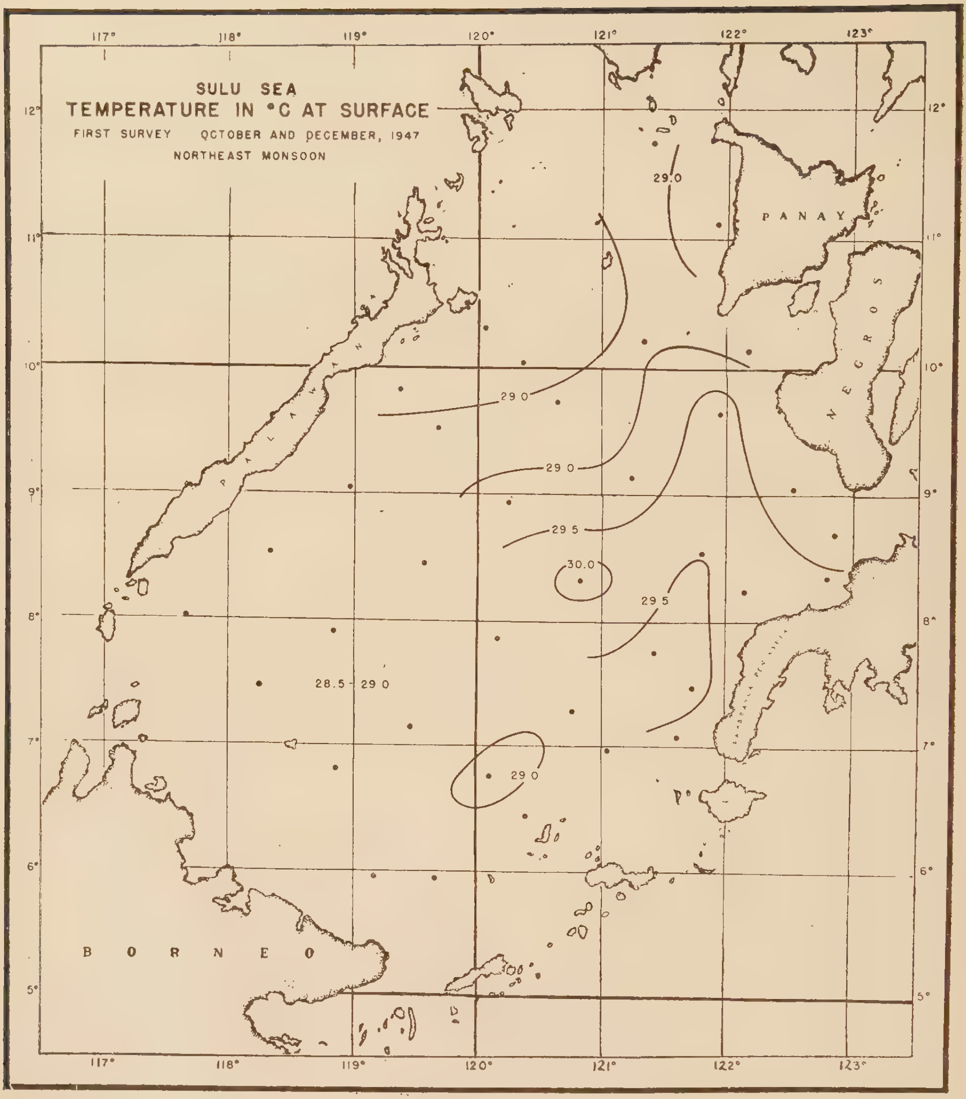

SULU SEA
TEMPERATURE IN °C AT SURFACE
FIRST SURVEY OCTOBER AND DECEMBER, 1947
NORTHEAST MONSOON
117°
118°
119°
120°
121°
122°
123°
12°
11°
10°
9°
8°
7°
6°
5°
PANAY
NEGROS
PALAWAN
BORNEO
ZAMBOANGA PENINSULA
29.0
29 0
29 0
29 5
30.0
29 5
28.5
29 0
29 0

CHART 8.—Temperature at the surface during October and December, 1947

CURRENTS: SOUTH-WEST MONSOON

At the Surface (Chart 5).—The dynamic topography for the Sulu Sea during the south-west monsoon is shown in Charts 5–7. Chart 5 presents the dynamic height anomalies for the surface relative to the 800-decibar surface. Although the current pattern has changed since the first survey, the two large eddies—the anticyclonic North Central Eddy and the cyclonic South Central Eddy—still dominate the pattern. The small anticyclonic eddy south of the South Central Eddy which occurred during the north-east monsoon persists during the south-west monsoon, but the two eddies to the north have disappeared.

The outstanding feature of the surface currents during the south-west monsoon is a flow of water from the China Sea between Palawan and Borneo. This water travels northeastward off the coast of Palawan. The fate of this water northward is uncertain. Probably part of it continues northward while another part turns south as part of the North Central Eddy. Another part of the south China Sea water turns southward as part of the South Central Eddy, and probably continues into the Celebes Sea through Sibutu Passage. The westerly current coming in from the Mindanao Sea and across the central Sulu Sea has much the same course as during the north-east monsoon until it meets the current from the China Sea, when it turns southward as part of the South Central Eddy. The strength of the surface current entering from the Mindanao Sea is much less during the south-west monsoon than during October and December.

At 100 Metres (Chart 6).—At the 100-decibar surface relative to the 800-decibar surface the South Central Eddy dominates the picture. The north-easterly current off Palawan is scarcely evident. Since the sill depths between Palawan and Borneo are less than 100 metres no water can enter at this level, and this probably explains the absence of an appreciable current off Palawan.

There seems to be little or no water entering from the Mindanao Sea at this level. The westerly central current is weak and consists actually of part of the South Central Eddy and the weak North Central Eddy. To the north there seems to be a transport of water eastward, but there are not sufficient stations in this area to indicate the flow accurately. In the south-eastern part of the Sulu Sea there are two small eddies, both of which were indicated at the surface. They are probably related to a complex interchange of water between the Sulu Sea and the Celebes Sea through the Sulu Archipelago.

At 200 Metres (Chart 7).—At the 200-decibar surface relative to the 800-decibar surface for the south-west monsoon the conditions are relatively uniform. There is a slight persistence of the South Central Eddy, but the indications of currents are negligible. Again there are not sufficient stations to the north to interpret the significance of the indications of an easterly current off Panay.

TEMPERATURE: NORTH-EAST MONSOON

At the Surface (Chart 8).—When the north-east half of the Sulu Sea was surveyed in October the surface temperatures were mostly between 29·0° C. and 30·0° C., with the highest temperature near the central part of the sea.

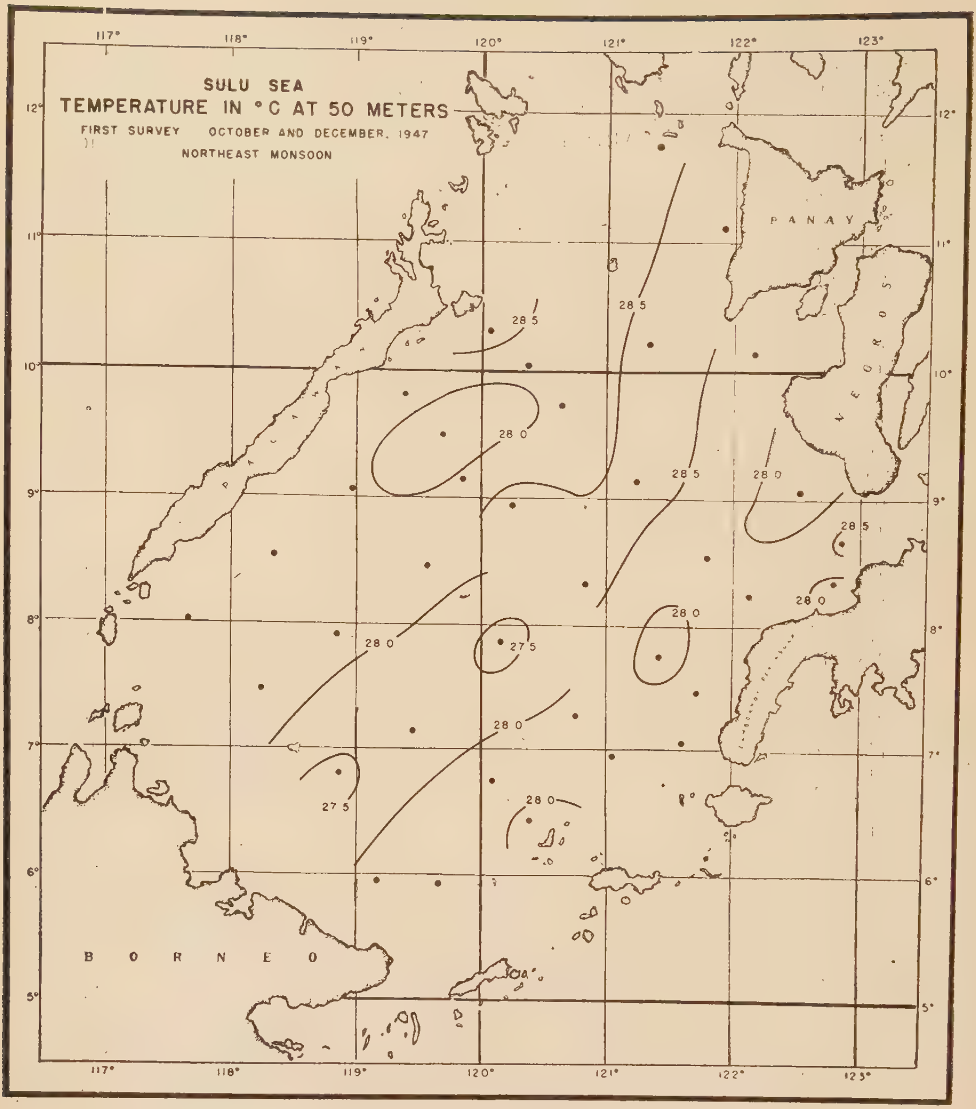

SULU SEA
TEMPERATURE IN °C AT 50 METERS
FIRST SURVEY OCTOBER AND DECEMBER, 1947
NORTHEAST MONSOON
PANAY
NEGROS
BORNEO
28 5
28 5
28 0
28 5
28 0
28 5
28 0
28 0
28 0
27 5
28 0
27 5
28 0
117°
118°
119°
120°
121°
122°
123°
12°
11°
10°
9°
8°
7°
6°
5°

CHART 9.—Temperature at 50 metres during October and December, 1947

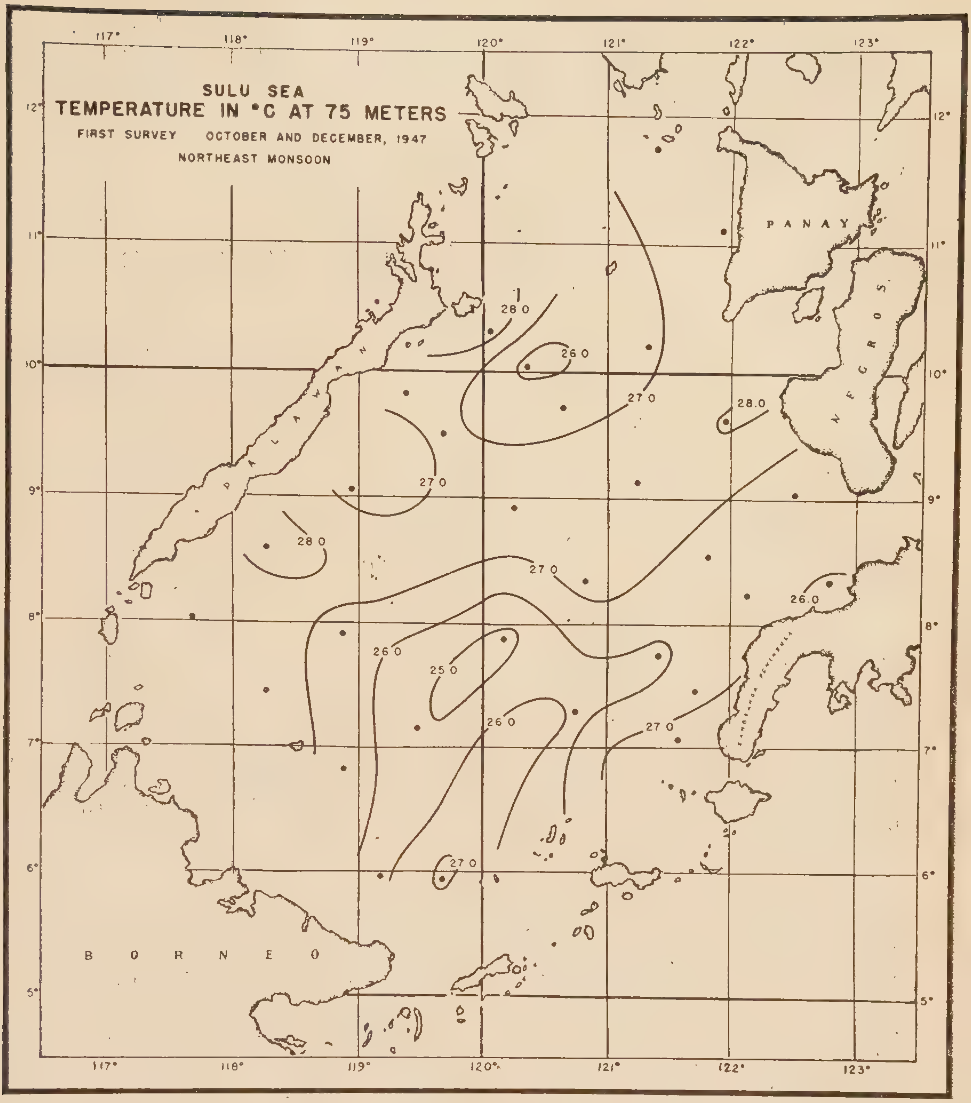

SULU SEA
TEMPERATURE IN °C AT 75 METERS
FIRST SURVEY OCTOBER AND DECEMBER, 1947
NORTHEAST MONSOON
117°
118°
119°
120°
121°
122°
123°
12°
11°
10°
9°
8°
7°
6°
5°
PALAWAN
PANAY
NEGROS
BORNEO
ZAMBOANGA PENINSULA
28.0
26.0
27.0
28.0
27.0
28.0
27.0
26.0
26.0
25.0
26.0
27.0
27.0

CHART 10.—Temperature at 75 metres during October and December, 1947

By the time the south-west half of the sea was surveyed in December the surface temperatures had dropped about 1° c., so that the values fell within the ranges 28·5° c. to 29·0° c. Because of this difference in range during the two parts of the survey it was not possible to connect the isotherms for the two halves of the sea. During the December survey the temperatures were so uniform over the area that almost no isotherms with 0·5° c. interval could be drawn.

At 50 Metres (Chart 9).—At a depth of 50 metres this difference in temperature for the October and December surveys is still apparent. In the central part of the sea the difference in temperature between the two areas is about 0·5° c. The temperature throughout the Sulu Sea at 50 metres during the October and December surveys were fairly uniform, lying within the range 27·5° c. to 29·0° c. and were only from 0·5° to 1·0° lower than at the surface. No complex patterns had developed.

At 75 Metres (Chart 10).—The distribution of temperature at the 75-metre level shows two striking features. First, the general cooling which took place in the surface layer between October and December did not extend to this depth so that there is no difficulty in connecting the isotherms for the October and December surveys. The second feature is the complex temperature pattern as contrasted with the distribution of temperature at the 50-metre level and at the surface.

The pattern in general corresponds to the pattern of current eddies, which were described above for the surface and 100-metre levels for this season of the year. The South Central Eddy is characterized by low temperatures; the North Central Eddy by high temperatures. Each of the other eddies is defined by characteristic isotherms. The highest temperature at this level was 28·20° c. off southern Palawan, although a temperature of 28·01° c. was found in the North Central Eddy. The lowest temperature at this level was 24·63° c. which occurred in the South Central Eddy.

At 100 Metres (Chart 11).—At the 100-metre level during the north-east monsoon the pattern of temperature distribution resembled that for the 75-metre level. The principal difference was a large centre of water of low temperature in the North. This is an expansion of the centre found somewhat more to the west at the 75-metre level. It almost crowded out the centre of warmer water of the North Central Eddy.

The difference between the patterns in the western part of the Sulu Sea for the 75-metre and 100-metre levels may be due to the fact that temperature data are not available for station 57 below a depth of 75 metres. This station is at latitude 08° 32′ N., longitude 118° 32′ E.

At 200 Metres (Chart 12).—At the 200-metre level the complexities so evident at the 75-metre and 100-metre levels have almost completely disappeared. Throughout the whole sea the temperature is near 15° c. and 16° c., except at one station in the north-west, where the temperature was 17·52° c.

Charts are not presented for levels below 200 metres. Temperatures are very uniform at deeper levels in the Sulu Sea. At 400 metres the range in horizontal distribution of temperature is less than 1·5° c., while at the 800-metre level the range is less than 0·1° c.

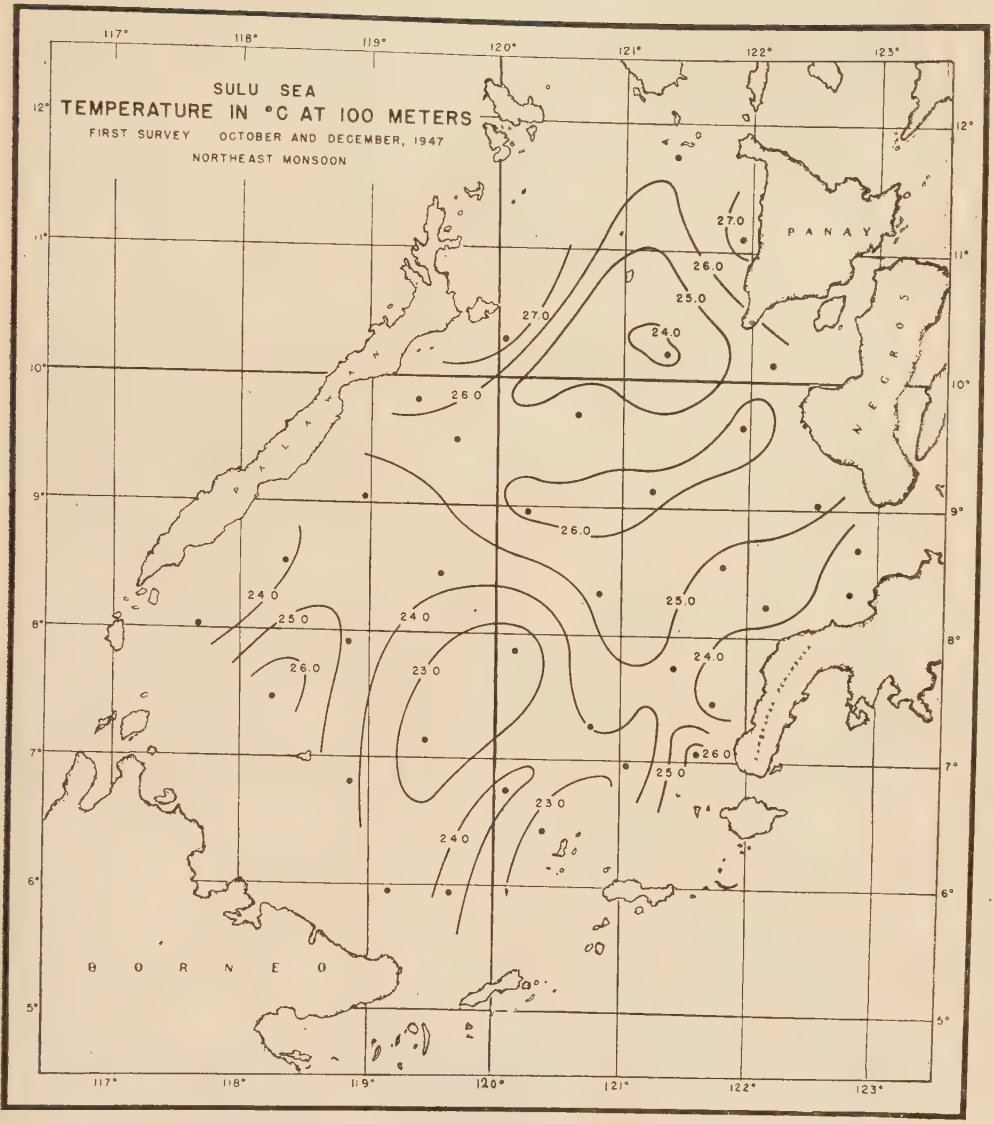

SULU SEA
TEMPERATURE IN °C AT 100 METERS
FIRST SURVEY OCTOBER AND DECEMBER, 1947
NORTHEAST MONSOON
117°
118°
119°
120°
121°
122°
123°
12°
11°
10°
9°
8°
7°
6°
5°
PANAY
NEGROS
PALAWAN
ZAMBOANGA PENINSULA
BORNEO
27.0
26.0
25.0
24.0
23.0

CHART 11.—Temperature at 100 metres during October and December, 1947

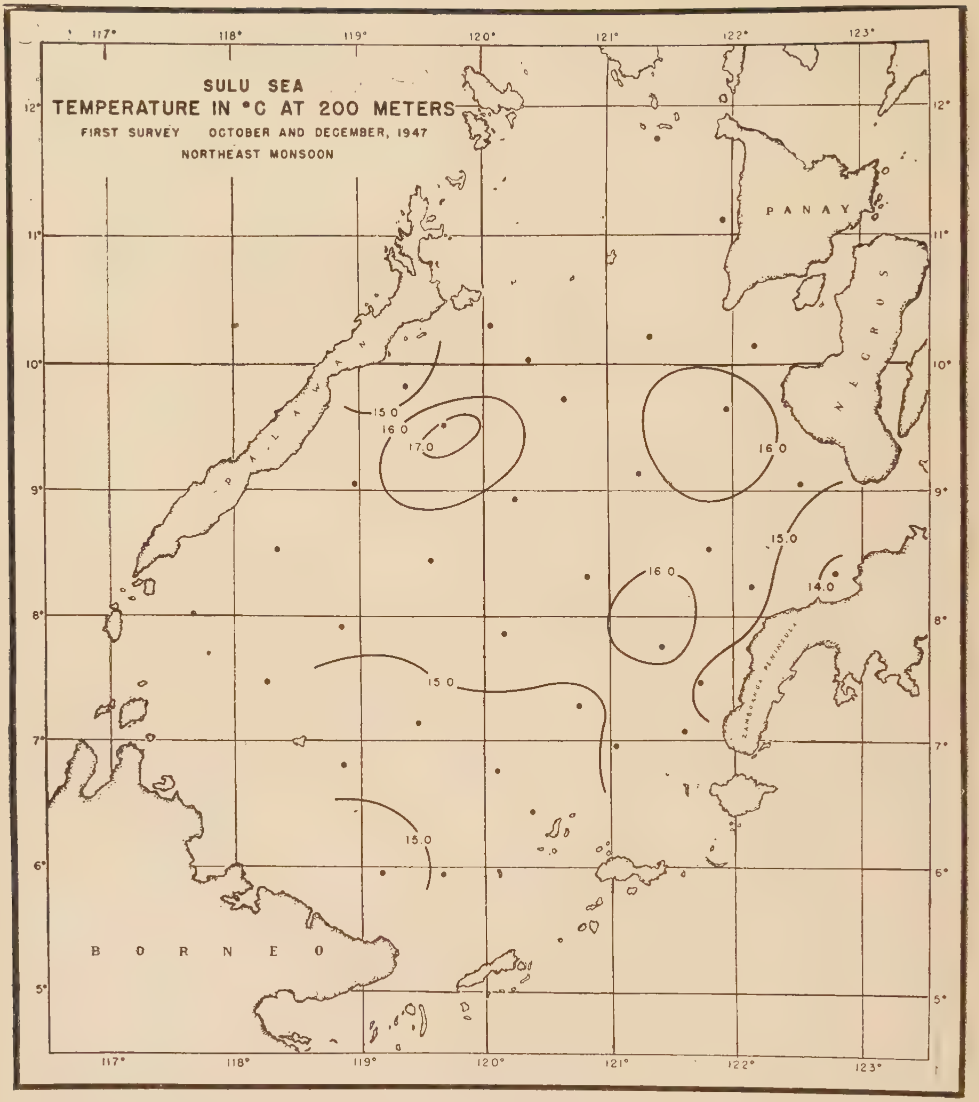

SULU SEA
TEMPERATURE IN °C AT 200 METERS
FIRST SURVEY OCTOBER AND DECEMBER, 1947
NORTHEAST MONSOON
117°
118°
119°
120°
121°
122°
123°
12°
11°
10°
9°
8°
7°
6°
5°
PANAY
NEGROS
PALAWAN
ZAMBOANGA PENINSULA
BORNEO
15.0
16.0
17.0
16.0
15.0
14.0
16.0
15.0
15.0

CHART 12.—Temperature at 200 metres during October and December, 1947

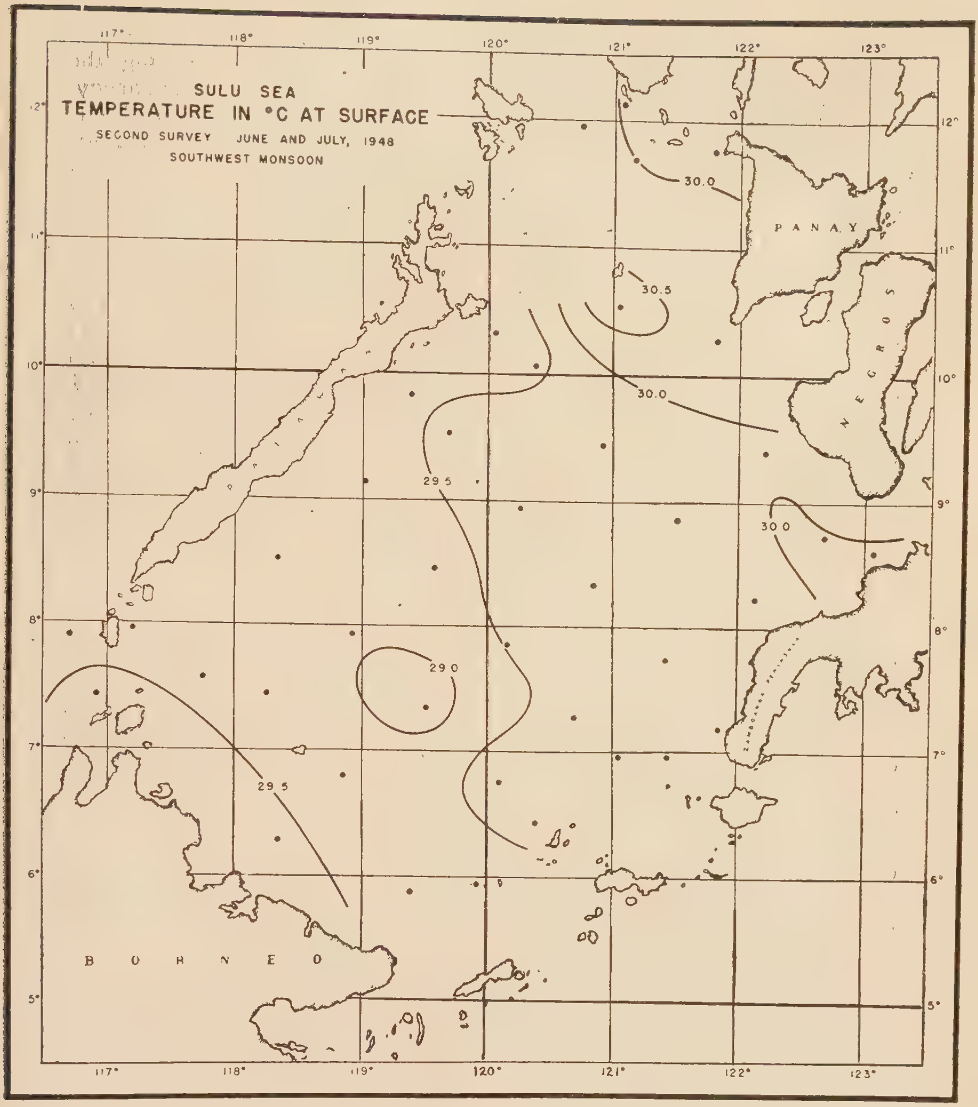

SULU SEA
TEMPERATURE IN °C AT SURFACE
SECOND SURVEY JUNE AND JULY, 1948
SOUTHWEST MONSOON
30.0
30.5
30.0
29.5
30.0
29.0
29.5
PANAY
NEGROS
PALAWAN
ZAMBOANGA PENINSULA
BORNEO
117°
118°
119°
120°
121°
122°
123°
12°
11°
10°
9°
8°
7°
6°
5°

CHART 13.—Temperature at the surface during June and July, 1948

TEMPERATURE : SOUTH-WEST MONSOON

At the Surface (Chart 13).—The surface temperatures during the second survey were not greatly different from those during the first survey. The values were mostly within one-half degree of 29·5° c. throughout. Temperatures were over 30·0° c. south of Negros and at two stations in the north. It is interesting to note that, although the north-eastern half of the area was surveyed in the middle of June and the south-western half during the middle of July, somewhat higher temperatures were found in the north-eastern portion as was the case during the north-east monsoon when the area was surveyed in October and December.

At 50 Metres (Chart 14).—The temperatures at the 50-metre level at this season showed a much more complex condition than at this level during the north-east monsoon, indicating that the depth of the wind layer was less than during the north-east monsoon. A centre of high temperatures in the north corresponding to the North Central Eddy had values above 29·0° c. Another such centre occurred to the south and corresponds to the anticyclonic eddy to the south of the South Central Eddy. Between these two centres there is a small centre of low temperature with values around 27·0° c. To the west is a centre with low values, less than 25·5° c. Comparatively low temperatures were found east of Palawan.

At 75 Metres (Chart 15).—The pattern of horizontal temperature distribution at the 75-metre level is similar to that at 50 metres, except that the centres of low and high temperature are not so pronounced. The highest value was 27·68° c. in the North Central Eddy ; the lowest value was 23·63° c. in the South Central Eddy. Lower temperatures were found at 75 metres west of Balabac Strait in the China Sea, but this cold water apparently did not enter the Sulu Sea. As at the 50-metre level, the water east of Palawan was colder than that farther east in the Sulu Sea.

An outstanding feature of the temperature distribution at 75 metres during the south-west monsoon is the lower values observed. Throughout most of the year the temperatures are from 0·5° to 1·0° lower than during the north-east monsoon. Along Palawan the difference is about 2·0° with temperatures near 25° c. during the south-west monsoon.

At 100 Metres (Chart 16).—The distribution of temperature at 100 metres during the south-west monsoon is dominated by a centre of low temperatures corresponding to the South Central Eddy. Values here are less than 21° c. At the 100-metre level, as at the 75-metre level, the temperatures during the south-west monsoon were lower than during the north-east monsoon.

At 200 Metres (Chart 17).—The temperatures at the 200-metre level are remarkably similar to those for this depth observed during the north-east monsoon. Apparently seasonal changes in the temperature of the Sulu Sea do not extend to the 200-metre level.

At the 400-metre level and the 800-metre level the horizontal distribution of temperature is just as uniform as at these levels during the north-east monsoon.

SALINITY : NORTH-EAST MONSOON

At the Surface (Chart 18).—The salinity in the eastern third of the Sulu Sea during the first survey was about 33·8 ‰. To the north-west and in the southern portion the values were near 33·2 ‰. A centre

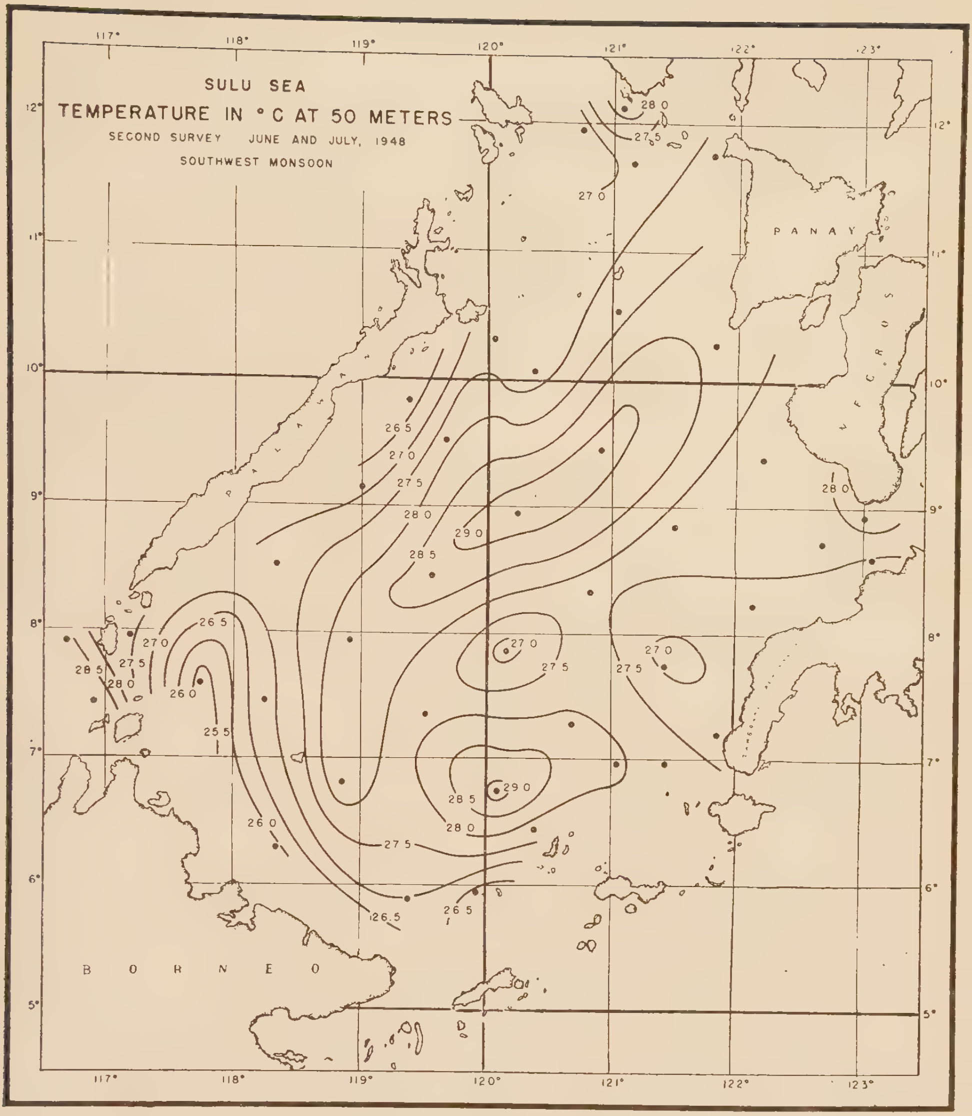
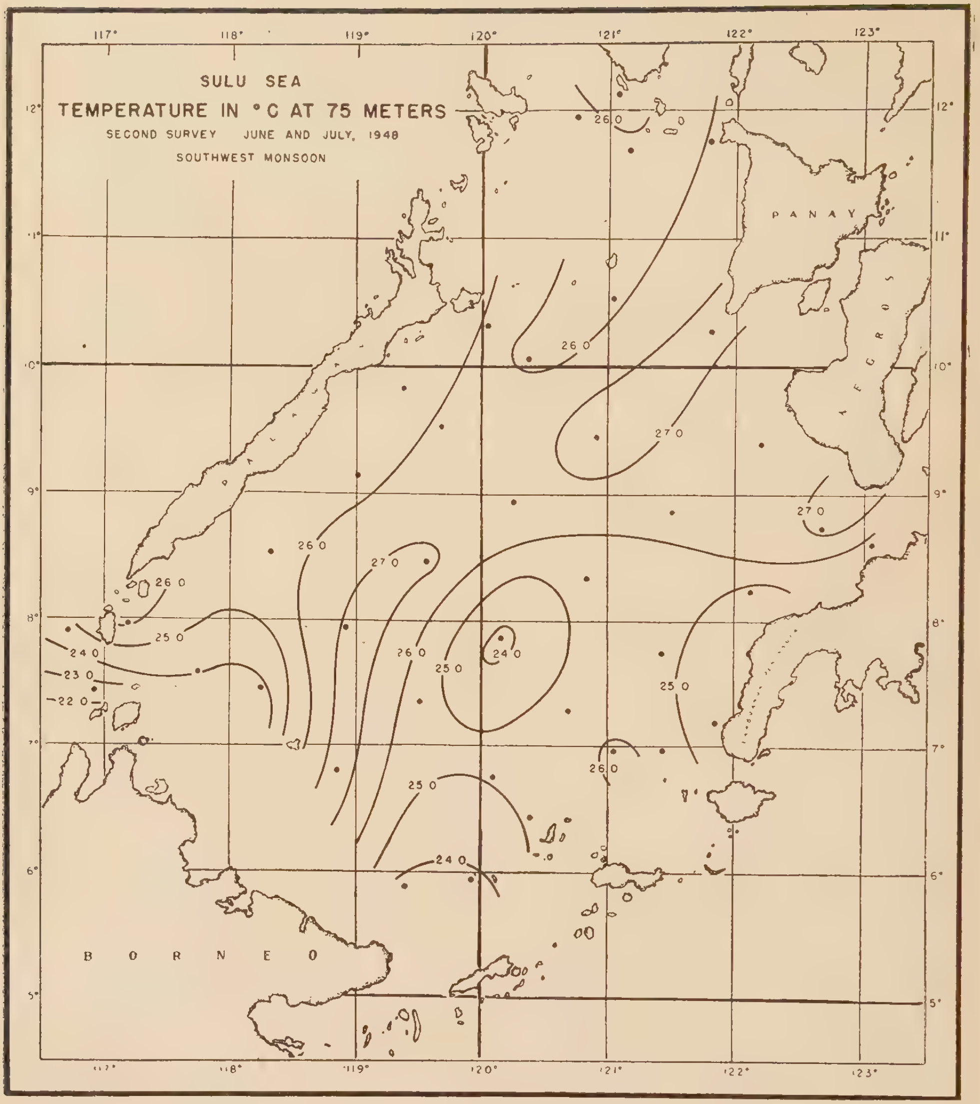

SULU SEA
TEMPERATURE IN °C AT 50 METERS
SECOND SURVEY JUNE AND JULY, 1948
SOUTHWEST MONSOON
PANAY
NEGROS
PALAWAN
BORNEO
117°
118°
119°
120°
121°
122°
123°
12°
11°
10°
9°
8°
7°
6°
5°
28 0
27 5
27 0
26 5
27 0
27 5
28 0
29 0
28 5
28 0
26 5
27 0
27 5
28 5
28 0
26 0
25 5
27 0
27 5
27 0
27 5
29 0
28 5
28 0
26 0
27 5
26.5
26 5

CHART 14.—Temperature at 50 metres during June and July, 1948



SULU SEA
TEMPERATURE IN °C AT 75 METERS
SECOND SURVEY JUNE AND JULY, 1948
SOUTHWEST MONSOON
117°
118°
119°
120°
121°
122°
123°
12°
11°
10°
9°
8°
7°
6°
5°
PANAY
NEGROS
PALAWAN
BORNEO
26 0
27 0
25 0
24 0
23 0
22 0

CHART 15.—Temperature at 75 metres during June and July, 1948

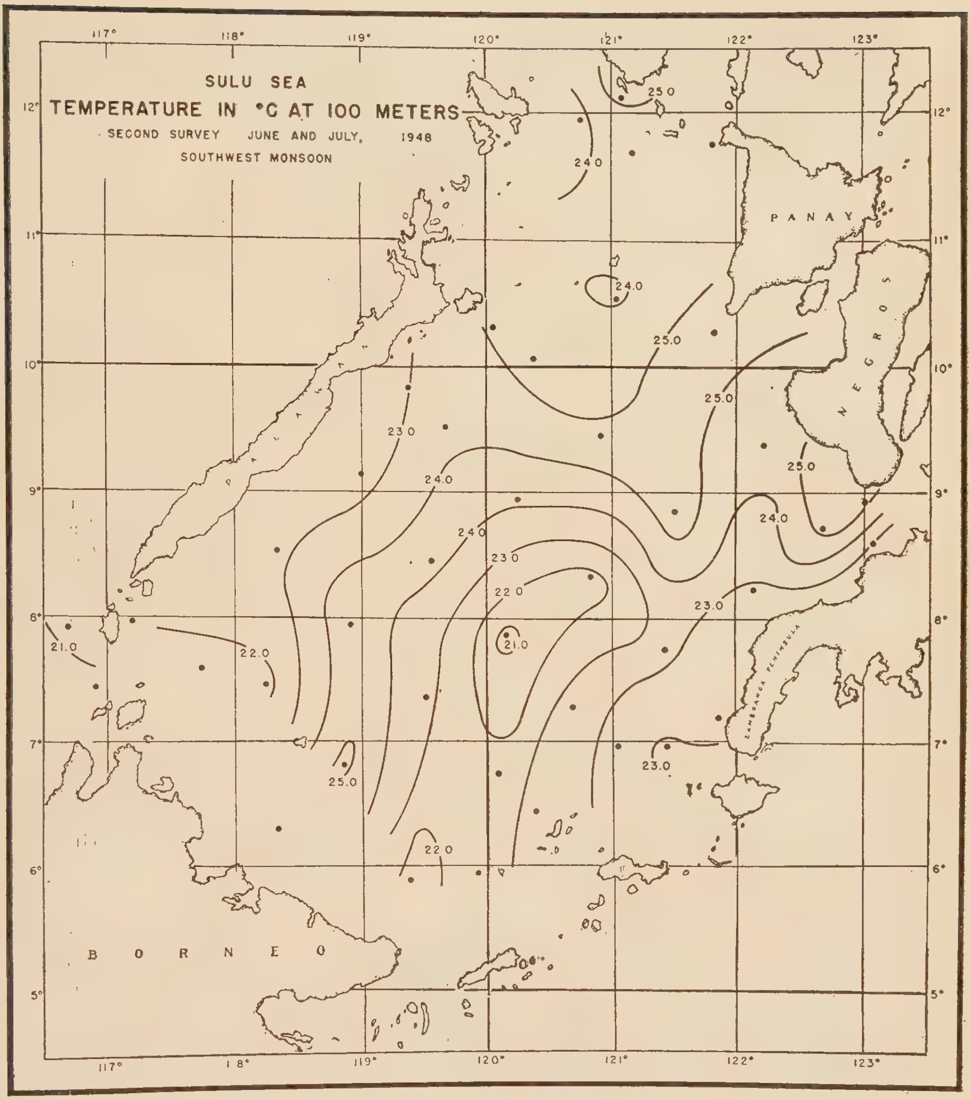

SULU SEA
TEMPERATURE IN °C AT 100 METERS
SECOND SURVEY JUNE AND JULY, 1948
SOUTHWEST MONSOON
117°
118°
119°
120°
121°
122°
123°
12°
11°
10°
9°
8°
7°
6°
5°
PANAY
NEGROS
PALAWAN
BORNEO
ZAMBOANGA PENINSULA
25.0
24.0
24.0
25.0
25.0
23.0
24.0
25.0
24.0
24.0
23.0
22.0
23.0
21.0
22.0
21.0
25.0
23.0
22.0

CHART 16.—Temperature at 100 metres during June and July, 1948

with values up to 34·0 $^{0}/_{00}$ occurred toward the west and extended as a tongue eastward. The values toward the China Sea were near 33·4 $^{0}/_{00}$. There is no indication of low salinity water entering from the China Sea, except at one station, where a value of 32·84 $^{0}/_{00}$ was found. This is in great contrast to conditions found during the south-west monsoon.

At 50 Metres (Chart 19).—At this level most of the water has a salinity of about 34·0 $^{0}/_{00}$. A number of centres with lower values, down to 33·6 $^{0}/_{00}$ or 33·4 $^{0}/_{00}$, occurred in various areas.

At 75 Metres (Chart 20).—At this level the salinity is 34·2 $^{0}/_{00}$ to 34·3 $^{0}/_{00}$ or slightly higher throughout most of the sea. Lower values were found to the south, and more especially to the west and along Palawan, where values as low as 33·7 $^{0}/_{00}$ were found at two stations.

At 100 Metres (Chart 21).—At this level the salinity distribution resembles that at 75 metres. There is a great uniformity of the water, with values mostly between 34·3 $^{0}/_{00}$ and 34·4 $^{0}/_{00}$, except along Palawan where the salinity is lower ; close to 34·0 $^{0}/_{00}$.

At 200 Metres (Chart 22).—At this level the horizontal distribution of salinity is practically uniform. The extreme range of salinity at this level is 0·09 $^{0}/_{00}$. In Chart 22 the contour interval is only 0·04 $^{0}/_{00}$. It will be noted that the salinity is everywhere close to 34·4 $^{0}/_{00}$.

Below the 200-metre level the salinity is extremely uniform with values between 34·4 $^{0}/_{00}$ and 34·5 $^{0}/_{00}$.

Salinity : South-west Monsoon

At the Surface (Chart 23).—During the June–July survey the salinity at the surface throughout the central and eastern parts of the sea was between 34·0 $^{0}/_{00}$ and 34·2 $^{0}/_{00}$. This is in contrast to much lower values found here during the previous survey when the salinity over the entire Sulu Sea was less than 34·0 $^{0}/_{00}$. The significance of this difference in salinity is discussed below.

Another prominent feature of the distribution of surface salinities during the June–July survey is the obvious effect of an influx of water from the China Sea. Salinities in the China Sea west of Balabac Strait were about 32·0 $^{0}/_{00}$. The effect of the influx of this water into the Sulu Sea can be seen almost half way to Zamboanga in the fan-shaped pattern of increase in salinity eastward. The pattern also indicates a division of the China Sea water into a northward flowing branch along the coast of Palawan and a southward branch.

At 50 Metres (Chart 24).—At this level the salinity is very uniform compared to the salinity at the surface at this season or at the same level during the north-east monsoon. All values are close to 34·2 $^{0}/_{00}$ or 34·3 $^{0}/_{00}$, except at Balabac Strait, where 34·0 $^{0}/_{00}$ was found at one station. Apparently the influx of water from the South China Sea is limited to a shallow layer less than 50 metres in thickness at this season.

At 75 Metres (Chart 25).—At this depth the salinities are as uniform as at the 50-metre level with values close to 34·3 $^{0}/_{00}$ and 34·4 $^{0}/_{00}$. This, again, is in contrast to conditions at this level during the north-east monsoon surveys, when lower values were found (about 33·6 $^{0}/_{00}$) at stations along the coast of Palawan (Chart 20).

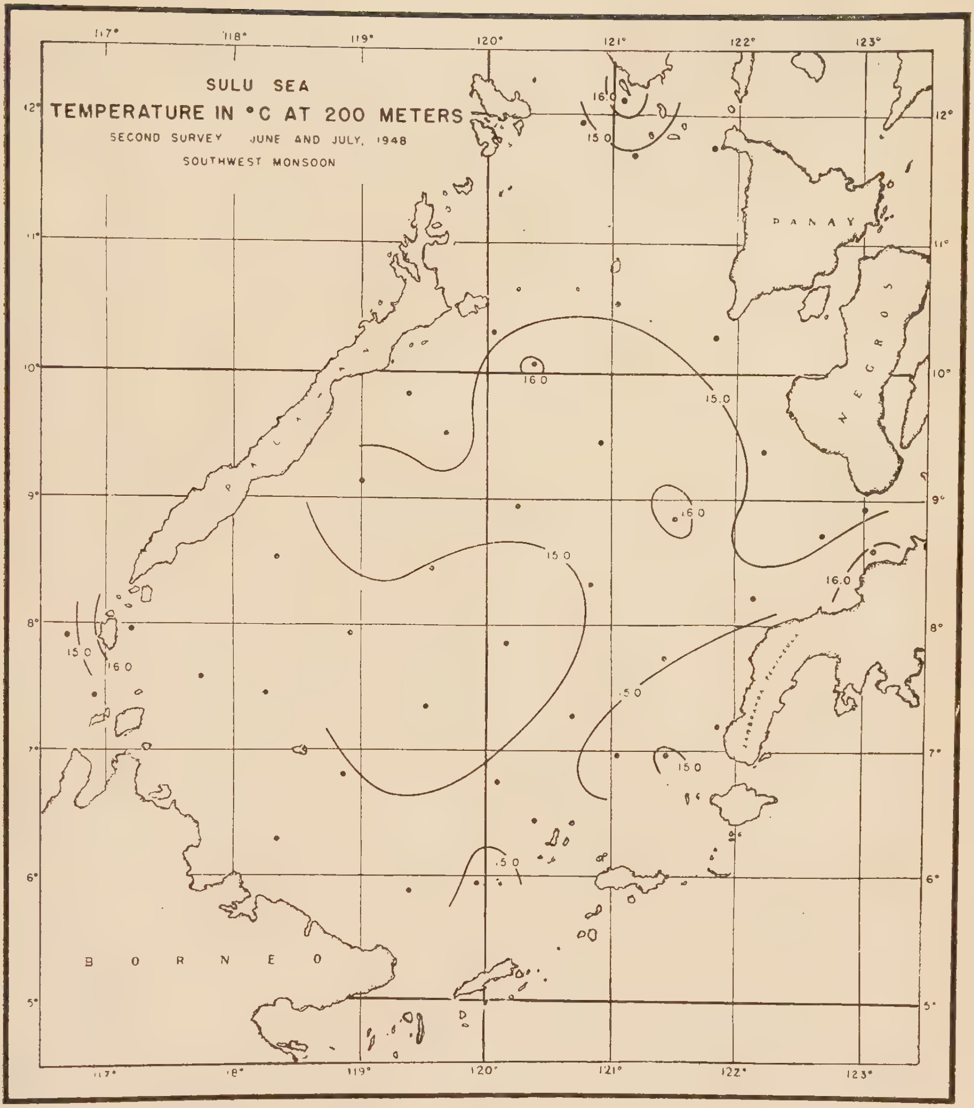

SULU SEA
TEMPERATURE IN °C AT 200 METERS
SECOND SURVEY JUNE AND JULY, 1948
SOUTHWEST MONSOON
PANAY
NEGROS
PALAWAN
BORNEO
ZAMBOANGA PENINSULA
117°
118°
119°
120°
121°
122°
123°
12°
11°
10°
9°
8°
7°
6°
5°
16.0
15.0

CHART 17.—Temperature at 200 metres during June and July, 1948

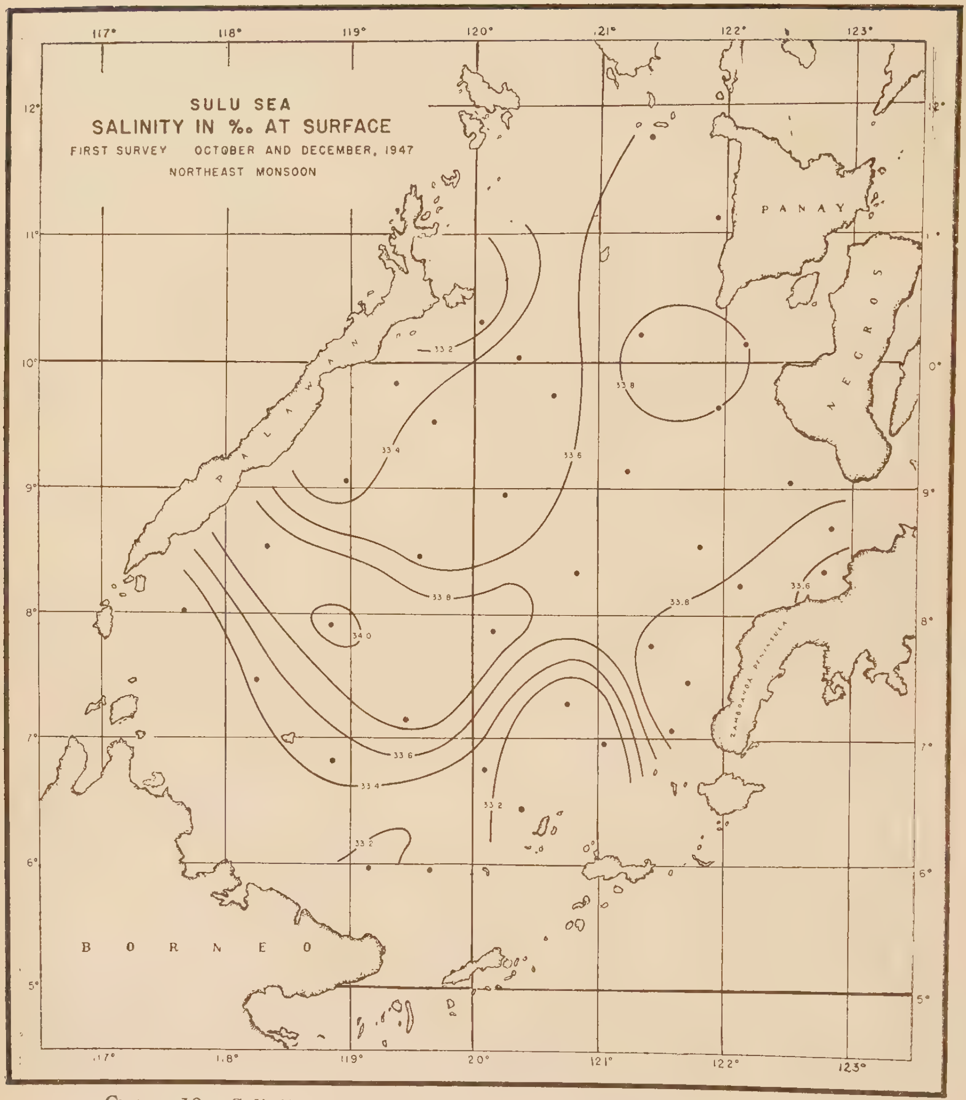

SULU SEA
SALINITY IN ‰ AT SURFACE
FIRST SURVEY OCTOBER AND DECEMBER, 1947
NORTHEAST MONSOON
117°
118°
119°
120°
121°
122°
123°
12°
11°
10°
9°
8°
7°
6°
5°
PALAWAN
PANAY
NEGROS
ZAMBOANGA PENINSULA
BORNEO
33.2
33.4
33.6
33.8
34.0

Chart 18.—Salinity at the surface during October and December, 1947

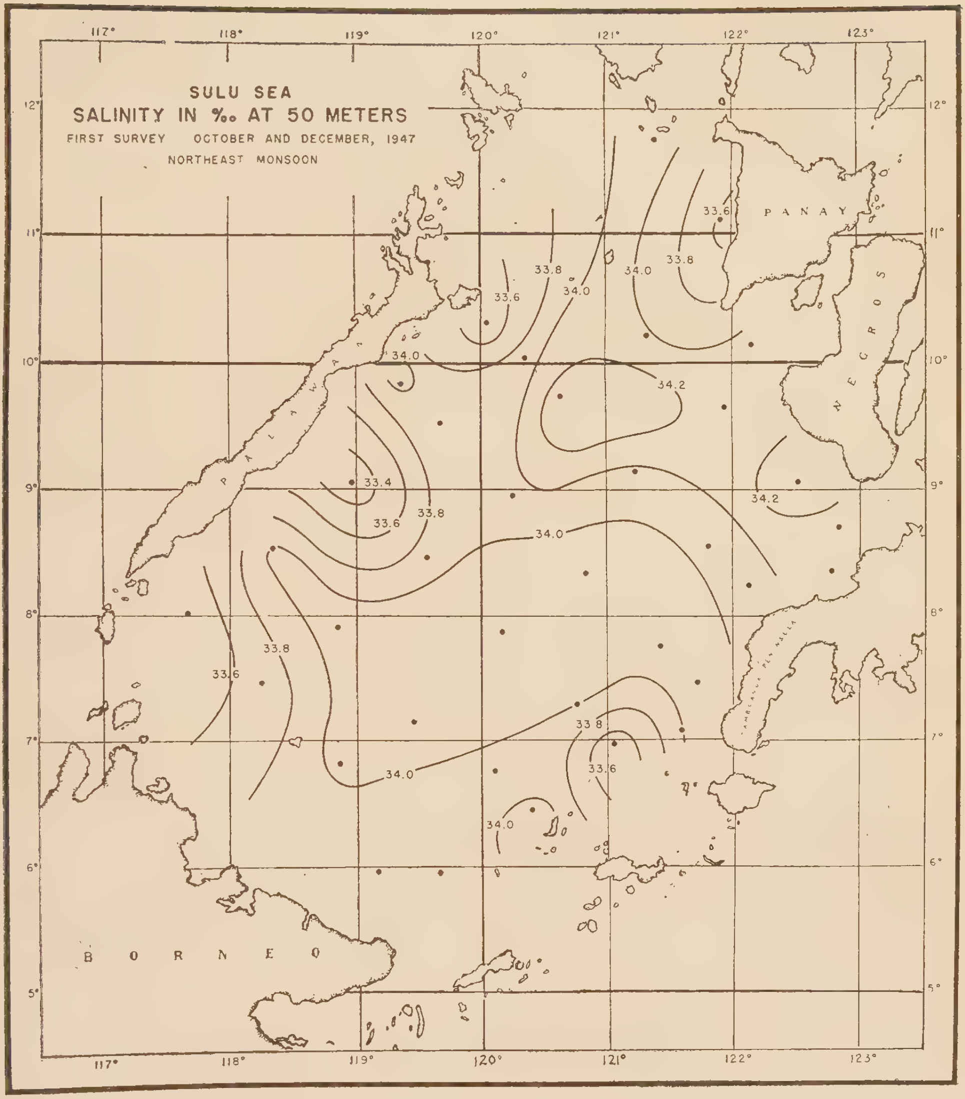

SULU SEA
SALINITY IN ‰ AT 50 METERS
FIRST SURVEY OCTOBER AND DECEMBER, 1947
NORTHEAST MONSOON
PANAY
NEGROS
PALAWAN
BORNEO
ZAMBOANGA PENINSULA
33.6
33.8
34.0
34.2
33.4
117°
118°
119°
120°
121°
122°
123°
5°
6°
7°
8°
9°
10°
11°
12°

Chart 19.—Salinity at 50 metres during October and December, 1947

At 100 Metres (Chart 26).—Throughout the area at this level the salinities were very uniform with values about the same as at the 75-metre level. There is no indication of the low-salinity water which was found off Palawan at this depth during the north-east monsoon (Chart 21).

At 200 Metres (Chart 27).—At this level the range of salinity values is 0·03 °/₀₀, from 34·42 °/₀₀ to 34·45 °/₀₀. This is even less than the range found at this level during the north-east monsoon.

SUMMARY OF SALINITY DISTRIBUTION

The study of the salinity distributions at the various levels during the two seasons brings out several important features.

The lower-surface salinities during the north-east monsoon may be due to local weather conditions, but is more likely the result of a lag in the changes of salinity which follow the changes in currents effected by the south-west monsoon. The south-west monsoon begins in May or June, at which time it can be expected that water from the China Sea will begin to enter the Sulu Sea. By July, when the " Baird " surveyed the south-western half of the Sulu Sea, this China Sea water will have exerted its influence almost halfway across the area, as shown by reduced salinities, but in June, when the " Baird " surveyed the north-eastern half of the sea, the water still had the high salinities characteristic of the north-east monsoon. The south-west monsoon ends about September in the north and about November in the south, and at this time the surface salinities throughout the Sulu Sea can be expected to have reached their lowest values. This is corroborated by the low surface salinity found by the " Snellius " is September.

The north-east monsoon begins in October toward the north and in December toward the south. Thus the conditions found by the " Baird " in October in the north-eastern half of the Sulu Sea are probably an expression of the conditions set up during the south-west monsoon. By December, when the " Baird " surveyed the south-western half of the area, the north-east monsoon probably was already effective in some areas, but oceanographic conditions were probably still in a transition toward the conditions characteristic of the north-east monsoon, which might be expected to reach a maximum about March.

" Dana " station 3685 occupied in April in the south-eastern Sulu Sea shows a high surface salinity and probably represents conditions more characteristic of the north-east monsoon.

The lower subsurface salinities along the east side of Palawan perhaps can be explained in much the same way. The reduction in salinity in June and July did not extend to the 50-metre level. It is probable that in the early part of the south-west monsoon the north-east current in this region is very shallow. During October and December—that is, during the beginning of the north-east monsoon—there are pockets of low-salinity water extending to 100 metres depth. Possibly the north-east current extends to 100 metres during the end of the south-west monsoon and is composed of low-salinity water characteristic of the South China Sea. As this current is obliterated during the north-east monsoon, complex eddies and remnants of China Sea water might be expected to persist for some time, creating conditions as found by the " Baird " in October and December.

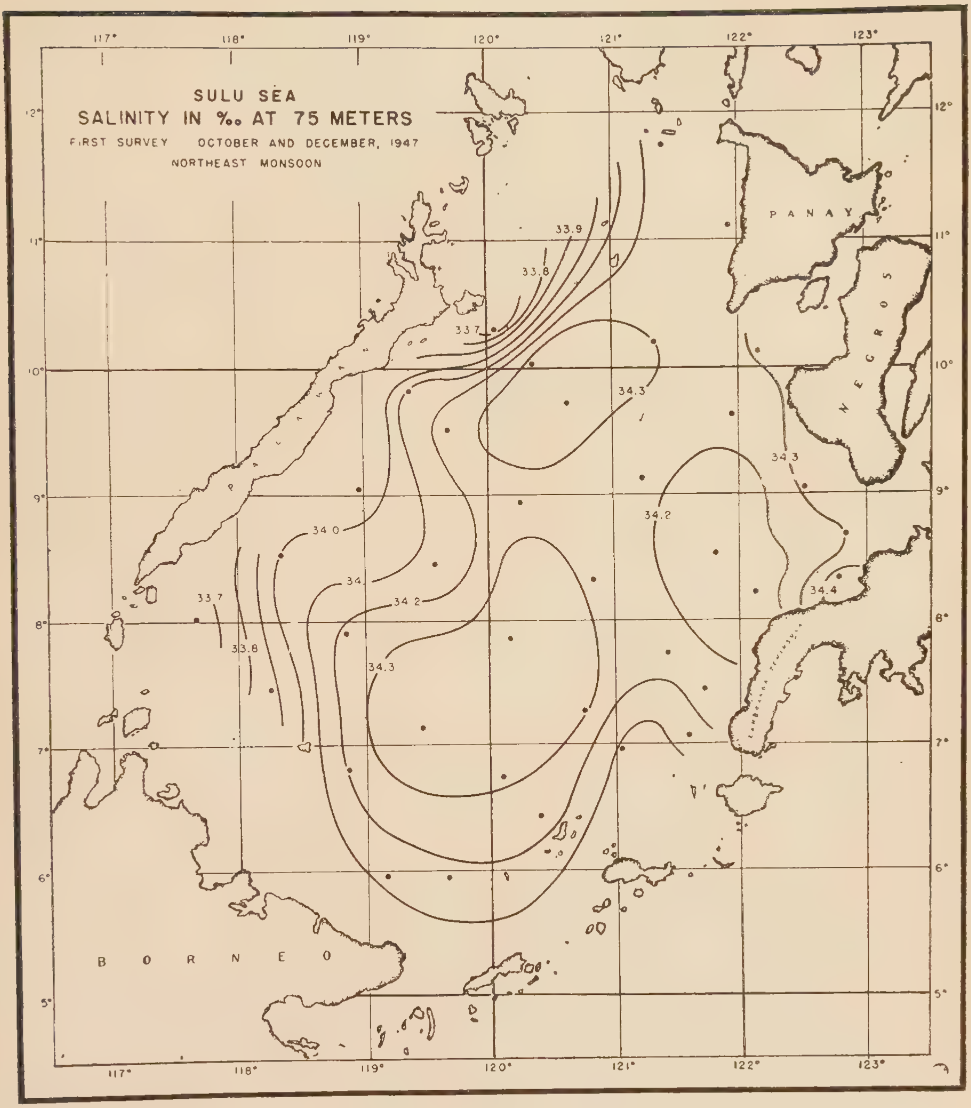

SULU SEA
SALINITY IN ‰ AT 75 METERS
FIRST SURVEY OCTOBER AND DECEMBER, 1947
NORTHEAST MONSOON
117°
118°
119°
120°
121°
122°
123°
12°
11°
10°
9°
8°
7°
6°
5°
PANAY
NEGROS
PALAWAN
BORNEO
ZAMBOANGA PENINSULA
33.9
33.8
33.7
34.3
34.3
34.2
34.0
34.
34.2
33.7
33.8
34.3
34.4

CHART 20.—Salinity at 75 metres during October and December, 1947

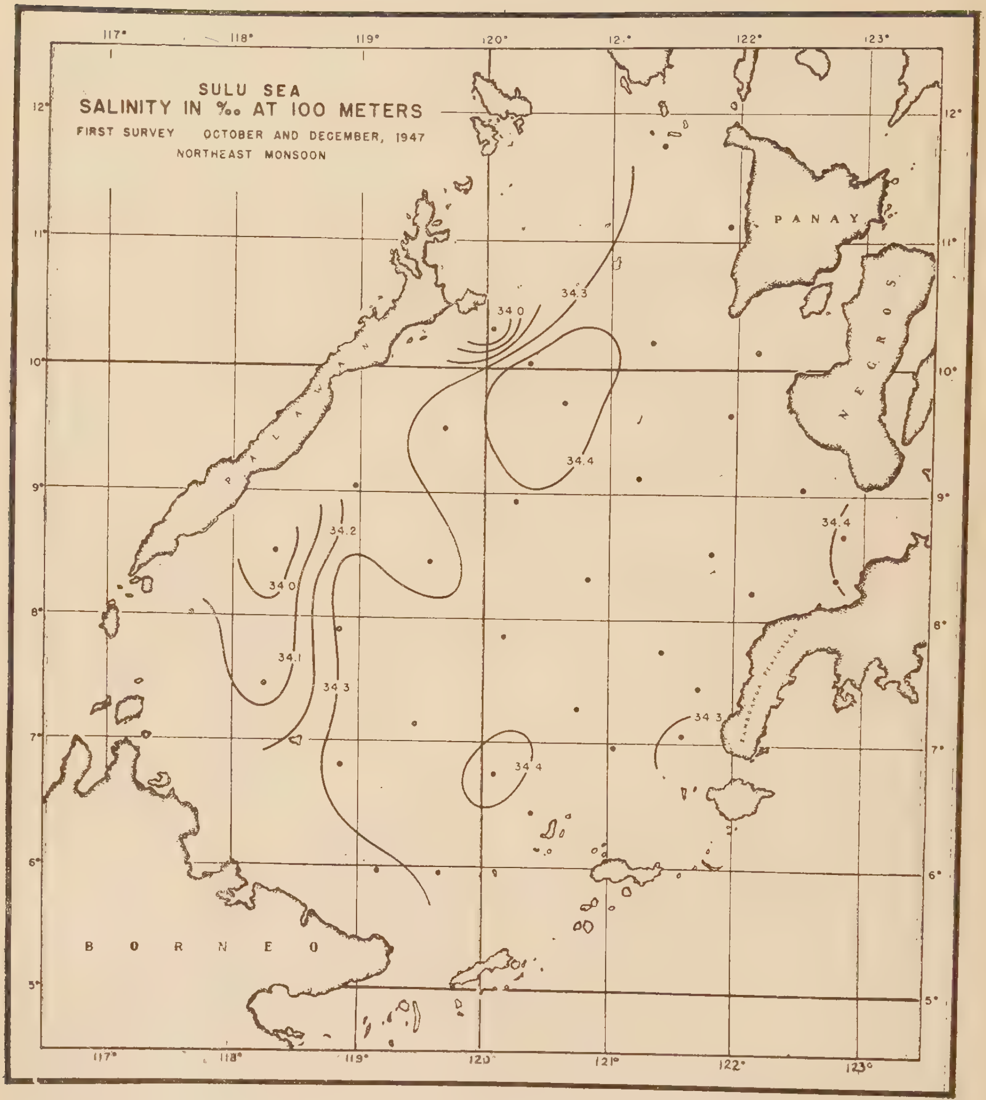

SULU SEA
SALINITY IN ‰ AT 100 METERS
FIRST SURVEY OCTOBER AND DECEMBER, 1947
NORTHEAST MONSOON
117°
118°
119°
120°
121°
122°
123°
12°
11°
10°
9°
8°
7°
6°
5°
PANAY
NEGROS
PALAWAN
BORNEO
ZAMBOANGA PENINSULA
34.0
34.3
34.4
34.2
34.1
34.3
34.4
34.4
34.3

CHART 21.—Salinity at 100 metres during October and December, 1947

THE DEEP WATER

The deep water of the Sulu Sea is very homogeneous in its characteristics. As pointed out above, at the 800-metre level the temperatures vary less than 0·1° c. and the salinities less than 0·05 $^0/_{00}$ from station to station. The uniformity with depth is equally striking. Between 800 metres and 4,000 metres the temperature does not vary as much as 0·5° c. nor the salinity as much as 0·5 $^0/_{00}$ (Fig. 1).

To date the " Baird " has occupied only one deep station in the Sulu Sea. Unfortunately, the salinity samples for this station above 400 metres were lost. In the presentation of conditions at this deep station, Station 37, salinity values for a nearby station, Station 36, have been substituted (Figs. 1 and 2).

The temperature of the deep water reached a minimum of 10·05° c. at a depth of about 1,400 metres, from which depth it increased to 10·48° c. at about 4,000 metres. This is an adiabatic increase in temperature and does not represent an instability of the water column. As shown in Fig. 1, the potential temperature decreases with increase in depth. This agrees with the observations of the " Snellius " in the Sulu Sea, as well as in the Mindanao Trench and other deeps of the western Pacific (Van Riel, 1934). It must be emphasized at this point that the " Baird " temperature data are accurate only in a relative sense. Exact absolute temperatures must await the calibration of the two reference thermometers. That the absolute values are not greatly in error is shown by the fact that Van Riel (1934) reports a minimum temperature in the Sulu Basin of 10·08° c. while the minimum temperature obtained by the " Baird " was 10·05° c.

According to Van Riel (1934), the deep water of the Sulu Basin is renewed from the north by inflow of water from the South China Sea. As pointed out above, the deepest sill separating the Sulu Sea from adjacent waters lies to the north in Mindoro Strait. The sill depth in that area is at about 450 metres. At this level in the South China Sea the water has a temperature of about 10° c. and salinity about 34·5 $^0/_{00}$ (Sverdrup, Fleming, and Johnson, 1942). These are the values obtained in the deep water of the Sulu Sea. Thus the temperature and salinity of the deep water of the Sulu Sea seems to be determined by the nature of the water entering over the northern sill.

The oxygen content of the deep water indicates that renewal of the basin water is fairly strong. The " Dana " reported uniform oxygen content below a depth of 400 metres. At " Baird " station 37 the oxygen content decreased to 2,000 metres, and then remained constant at 0·11 mg at/L to a depth of 4,000 metres. Although there was no increase toward the bottom characteristic of the open Pacific and South China Sea, yet there was no depletion of oxygen so characteristic of some isolated basins. A further study of the renewal of the deep water of the Sulu Sea must await more deep stations in the area.

The characteristics of the deep and intermediate water of the Sulu Sea are shown by the temperature-salinity curves. Figure 2 shows the temperature-salinity curves for " Dana " station 3685, " Snellius " station 65, and " Baird " stations 36 and 37 (data from Station 36 are used above 400 metres). The shapes of these curves are very similar except for values in the upper 100 metres. These differences can be

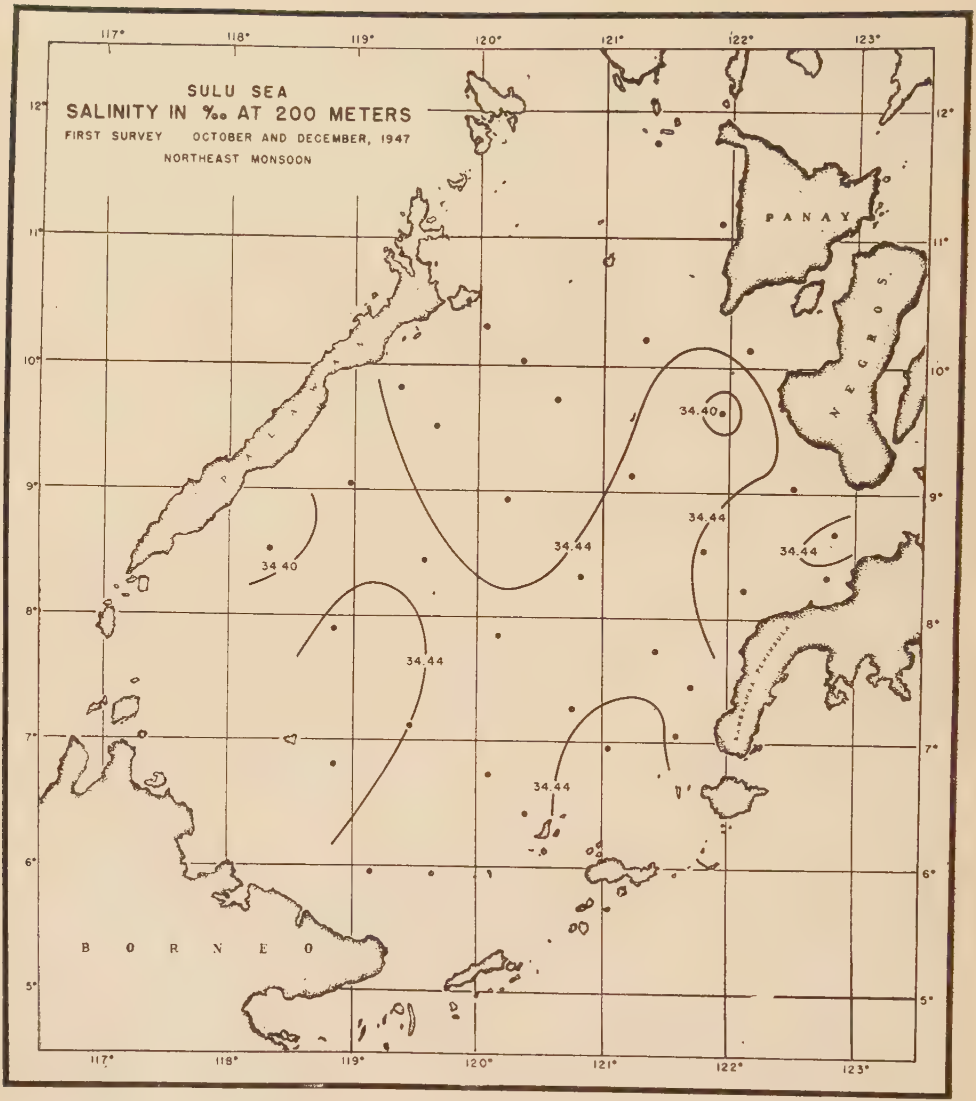

SULU SEA
SALINITY IN ‰ AT 200 METERS
FIRST SURVEY OCTOBER AND DECEMBER, 1947
NORTHEAST MONSOON
117°
118°
119°
120°
121°
122°
123°
12°
11°
10°
9°
8°
7°
6°
5°
PANAY
NEGROS
PALAWAN
ZAMBOANGA PENINSULA
BORNEO
34.40
34.44
34.40
34.44
34.44
34.44
34.44

CHART 22.—Salinity at 200 metres during October and December, 1947

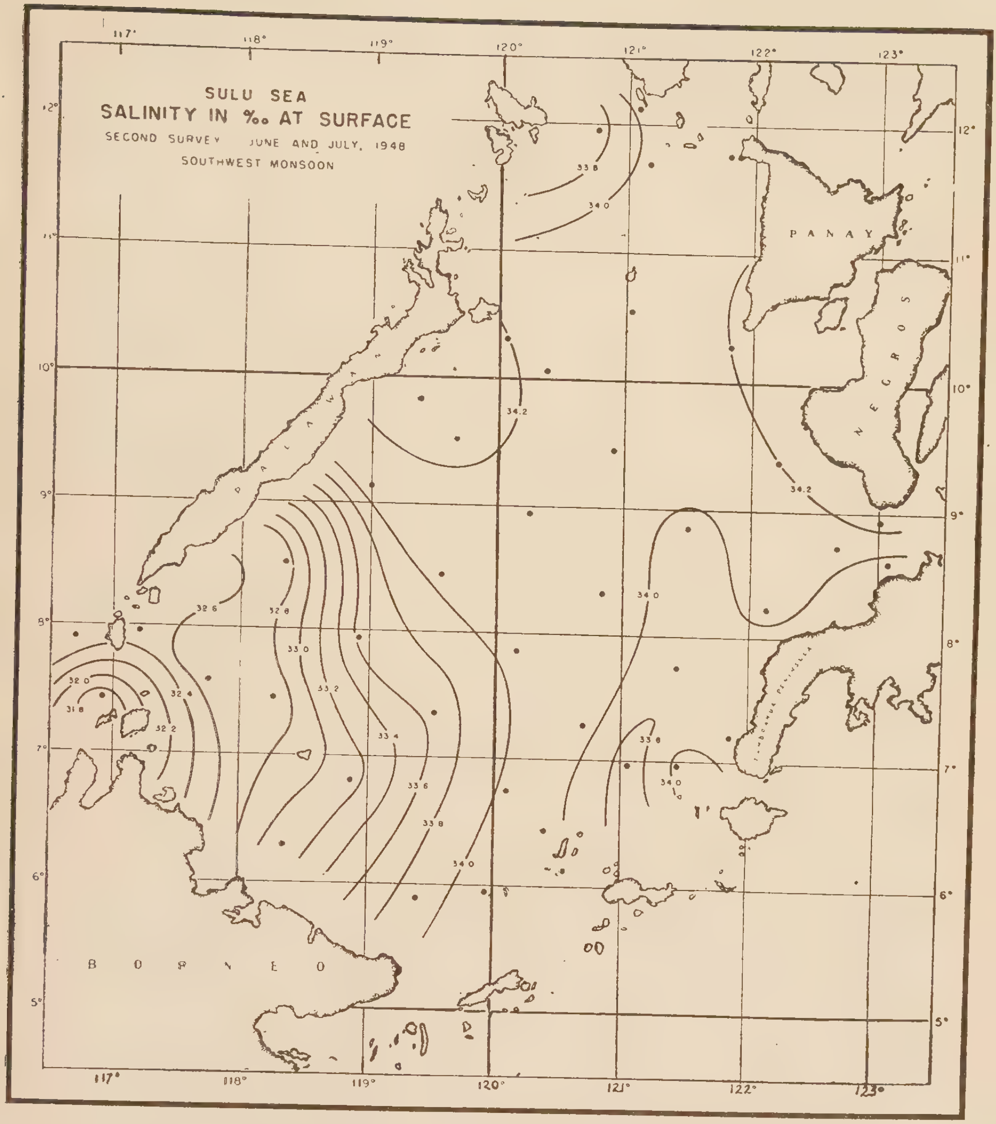

SULU SEA
SALINITY IN ‰ AT SURFACE
SECOND SURVEY JUNE AND JULY, 1948
SOUTHWEST MONSOON
PANAY
NEGROS
PALAWAN
BORNEO
ZAMBOANGA PENINSULA
117°
118°
119°
120°
121°
122°
123°
12°
11°
10°
9°
8°
7°
6°
5°
33.8
34.0
34.2
32.6
32.8
33.0
33.2
33.4
33.6
33.8
34.0
32.0
31.8
32.4
32.2
34.2
34.0
33.8
34.0

CHART 23.—Salinity at the surface during June and July, 1948 explained by the seasons in which the stations were occupied. The "Dana" data are for April, when the high salinities of the north-east monsoon still persisted. The "Snellius" station was occupied in September, when the water was of low salinity characteristic of the south-west monsoon. The "Baird" curve is significantly different in showing high temperatures in the upper layers. This station was occupied in October, 1947, when the temperatures were very high. Curves for "Baird" stations occupied in December resemble closely the "Dana" curve.

In the Sulu Sea there is no indication of a salinity maximum at the 100 to 200 metre level as found in the western Pacific. The Sulu Sea is effectively isolated from the Pacific at these levels. The South China Sea, with which it is in communication at this depth, does not have this layer of high salinity.

The study of the data on the chemical constituents which are of biological importance such as oxygen, phosphate, silicate, &c., has not been completed. A knowledge of the distribution of these substances throughout the waters is of great importance to an understanding of the biological conditions, and the "Baird" data are expected to be of considerable significance in this connection.

Plankton collections also are being made and are being studied in relation to the distribution of specific chemical substances. Both the hydrographic conditions, *per se*, and the plankton factors are related to the production and distribution of fish.

It is confidently hoped that some relationships between all these various factors will be demonstrated before the Philippine investigations are completed.

SUMMARY

1. This report is based on data collected by the "Spencer F. Baird" on four cruises to the Sulu Sea, constituting two surveys—the first during the early part of the north-east monsoon, in October and December, 1947; the second during the early part of the south-west monsoon, in June and July, 1948. Seventy-nine stations were occupied, at which serial temperatures and water samples were collected.

2. The Sulu Sea is an enclosed basin with maximum sill depth of 450 metres between it and the South China Sea to the north. It joins this sea to the west over a sill less than 100 metres in depth. Communication with the open Pacific is at still shallower depths, but a connection with the Celebes Sea to the south exists to a depth of 275 metres.

3. The surface currents in the Sulu Sea, as indicated by studies of dynamic topography, are dominated by two large eddies—a North Central Eddy and a South Central Eddy. These and a flow of water from the Mindanao Sea appear to be permanent features of the surface circulation.

4. During the early part of the south-west monsoon there is a strong inflow of water from the South China Sea which very noticeably lowers the surface salinities.

5. During the south-west monsoon a north-easterly current flows along the coast of Palawan.

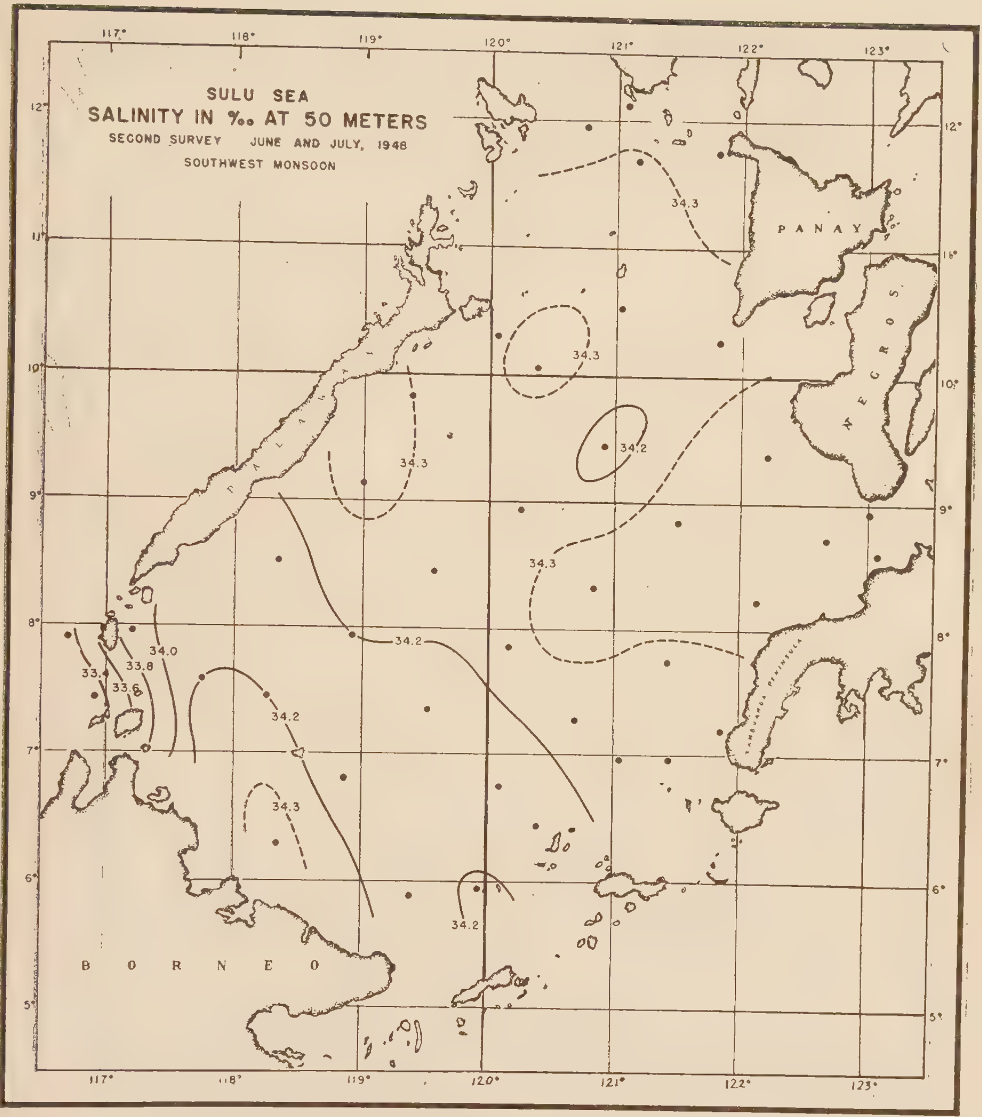

SULU SEA
SALINITY IN ‰ AT 50 METERS
SECOND SURVEY JUNE AND JULY, 1948
SOUTHWEST MONSOON
117°
118°
119°
120°
121°
122°
123°
12°
11°
10°
9°
8°
7°
6°
5°
PANAY
NEGROS
PALAWAN
ZAMBOANGA PENINSULA
BORNEO
34.3
34.3
34.3
34.2
34.3
34.2
34.0
33.8
33.4
33.6
34.2
34.3
34.2

CHART 24.—Salinity at 50 metres during June and July, 1948

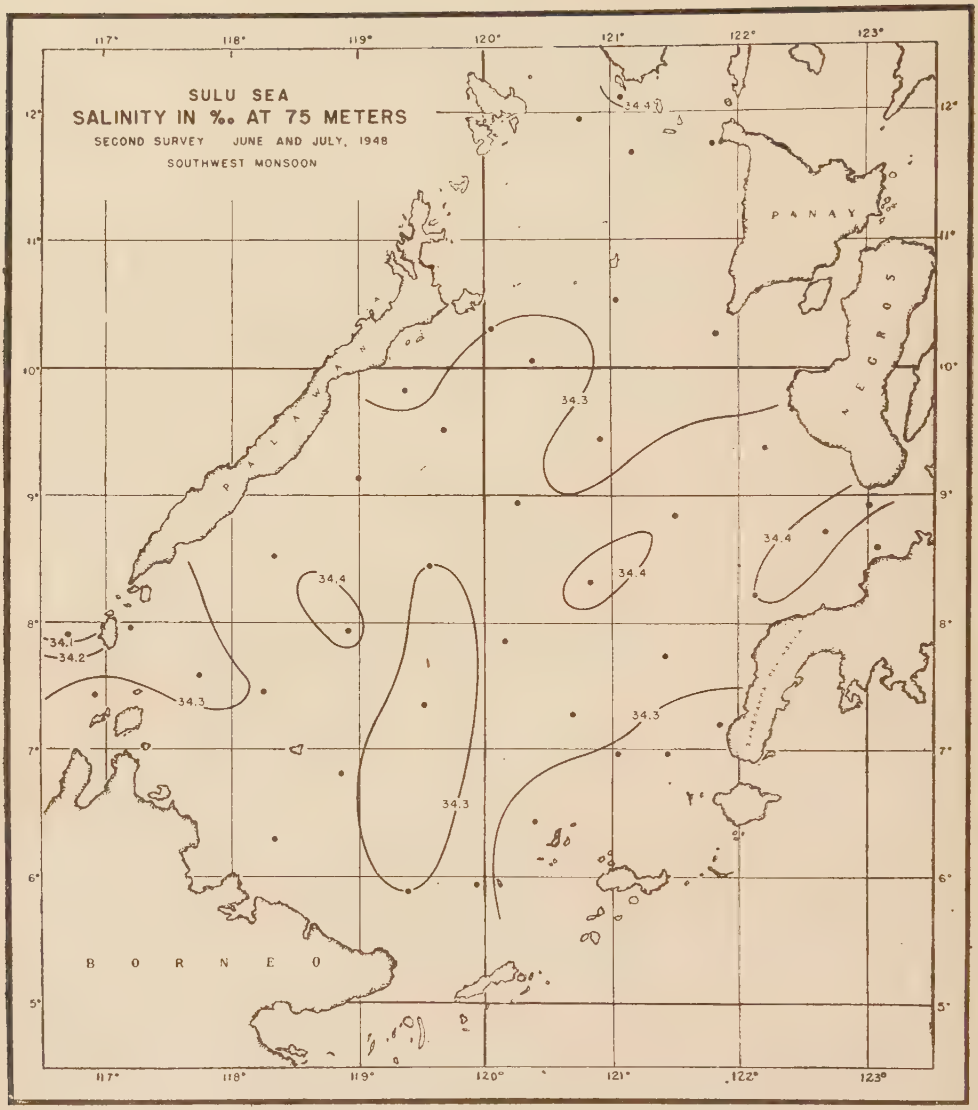

SULU SEA
SALINITY IN ‰ AT 75 METERS
SECOND SURVEY JUNE AND JULY, 1948
SOUTHWEST MONSOON
117°
118°
119°
120°
121°
122°
123°
12°
11°
10°
9°
8°
7°
6°
5°
PALAWAN
PANAY
NEGROS
ZAMBOANGA PENINSULA
BORNEO
34.4
34.3
34.4
34.4
34.4
34.1
34.2
34.3
34.3
34.3

Chart 25.—Salinity at 75 metres during June and July, 1948

6. Seasonal changes in wind direction create very complex conditions in the upper water layers, but seasonal changes extend only to a depth between 100 and 200 metres.

7. The deep water of the Sulu Sea below a depth of 800 metres is extremely uniform in temperautre and chemical composition. There is an adiabatic increase in temperature toward the bottom.

Bibliography

Brennecke, W. (1915) : Ozeanographische arbeiten S.M.S. Planet im Westlichen Stillen Ozean 1912–1913. *Ann. Hydrog.*, v. 43, 145–158.

Deacon, G. E. R. (1937) : The Hydrology of the Southern Ocean. *Discovery Reports*, v. 15, p. 1–124, plates I-XLIV, 1937. Cambridge Univ. Press, London.

Leipper, Dale, and William Wood (1947) : Temperature and Salinity of Philippine Waters. *Scripps Inst. Oceanography. Oceanographic Report* No. 4, 47 pp. (mimeographed).

Schott, G. (1914) : Adiabatishce Temperaturanderung in grossen Meerestiefen. *Ann. d. Hydrogr. u. Mar. Meteorol.*, p. 321–340.

Selga, M. (1931a) : Windroses of Ideal Marine Stations In and Near the Philippines. *Pub. Manila Observatory*, v. 3, no. 2. 35–57.

——— (1931b) : Sea Surface Temperatures in the Philippines. *Ibid.*, No. 3. 59–139.

——— (1931c) : Variation of the Temperature of the Sea With Depth in the Philippines. *Ibid.*, No. 4. 141–153.

——— (1931d) : Observations of the Salinity of the Sea in the Philippines. *Ibid.*, No. 5. 155–165.

——— (1931e) : The Deeps of the Philippines. *Ibid.*, No. 8. 185 195.

Sverdrup, H. U. ; Johnson, M. W. ; and Fleming, R. H. (1942) : *The Oceans.* 1,087 pp. New York.

Thomsen, H. (1935) : Entstehung and Verbreitung einiger charakteristischer Wassermassen in dem Indischen und sudlichen Pazifischen Ozean. *Ann. d. Hydrogr. u. Mar. Meteorl.*, p. 293–305.

Van Riel, P. M. (1934) : The Bottom Configuration in Relation to the Flow of the Bottom Water. *Snellius Exped. in the eastern part of the Netherlands East Indies 1929–1930*, v. 2, ch. 2, Oceanography, 63 pp.

Wüst, G. (1929) : Schichtung und Tiefenzirkulation des Pazifischen Ozeans. *Berlin Univ. Institut f. Meereskunde, N. F., A. Geogra. -naturwiss. Reihe*, Heft 20, 63 pp.

Summary of Discussion

Dr. Graham emphasized that he would welcome contacts with any other oceanographers outside Manila, and that any suggestions as to data or interpretation of data would be most helpful. Dr. Bruun compared the relation of the Sulu Sea to adjacent waters, with that of the Mediterranean to the Atlantic. He suggested that further examination be made of the animal life, at greater depths if possible. He discussed bathypelagic hauls and the temperature factor in deep waters. The deep water of the Mediterranean was too warm, but it was suggested that in the Sulu Sea the larvæ might occupy surface waters and the adults the colder depths. Deep-sea angler fishes and the deep-sea eel family were cited.

Dr. Hubbs pointed out that at the Fourth Congress a special province had been established for the areas of deep water. There was a great uniformity of temperature in the great depths, and a high degree of endemism in the bottom fishes. In the Macrourid group thirty new

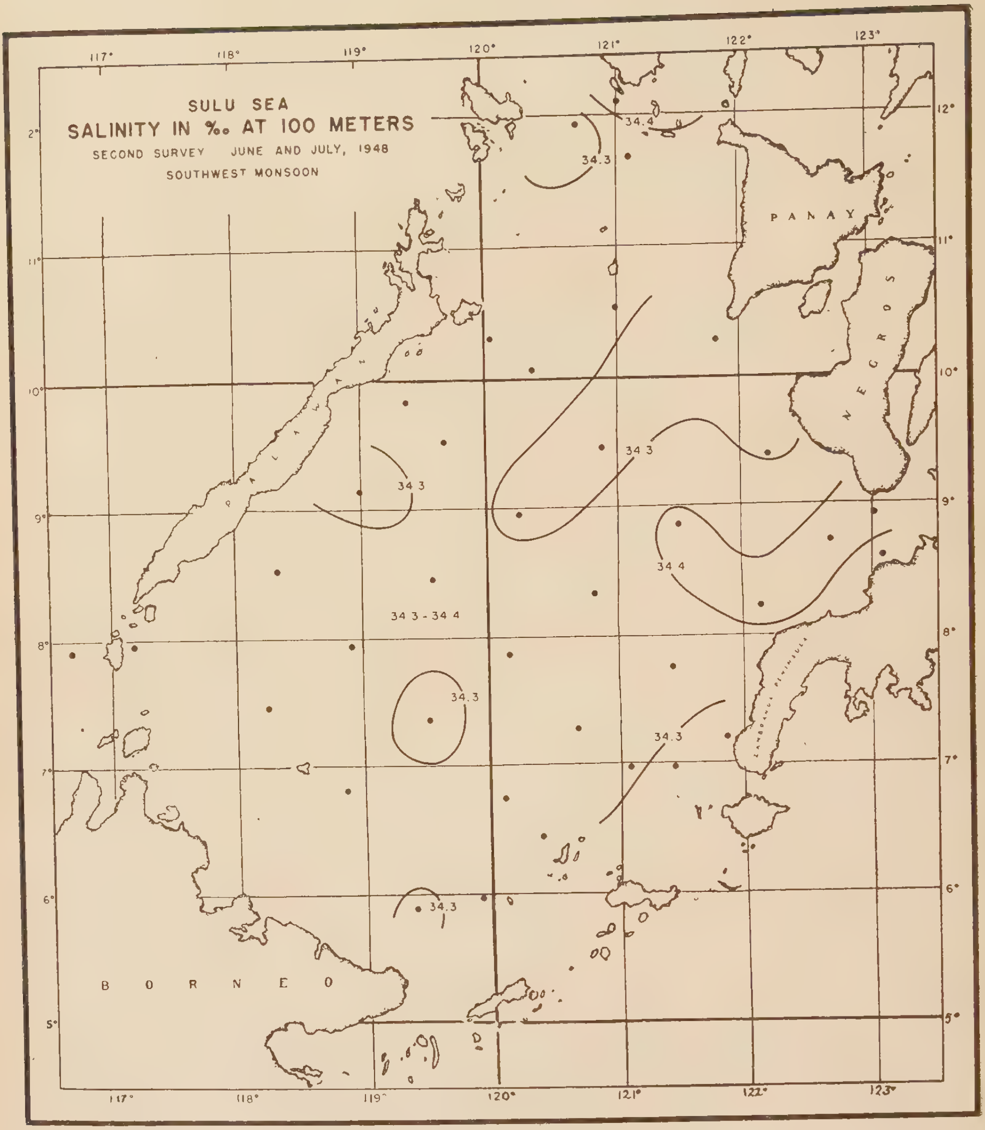

SULU SEA
SALINITY IN ‰ AT 100 METERS
SECOND SURVEY JUNE AND JULY, 1948
SOUTHWEST MONSOON
117°
118°
119°
120°
121°
122°
123°
12°
11°
10°
9°
8°
7°
6°
5°
PANAY
NEGROS
PALAWAN
ZAMBOANGA PENINSULA
BORNEO
34.4
34.3
34 3
34 4
34 3 - 34 4
34.3
34.3
34.3

CHART 26.—Salinity at 100 metres during June and July, 1948

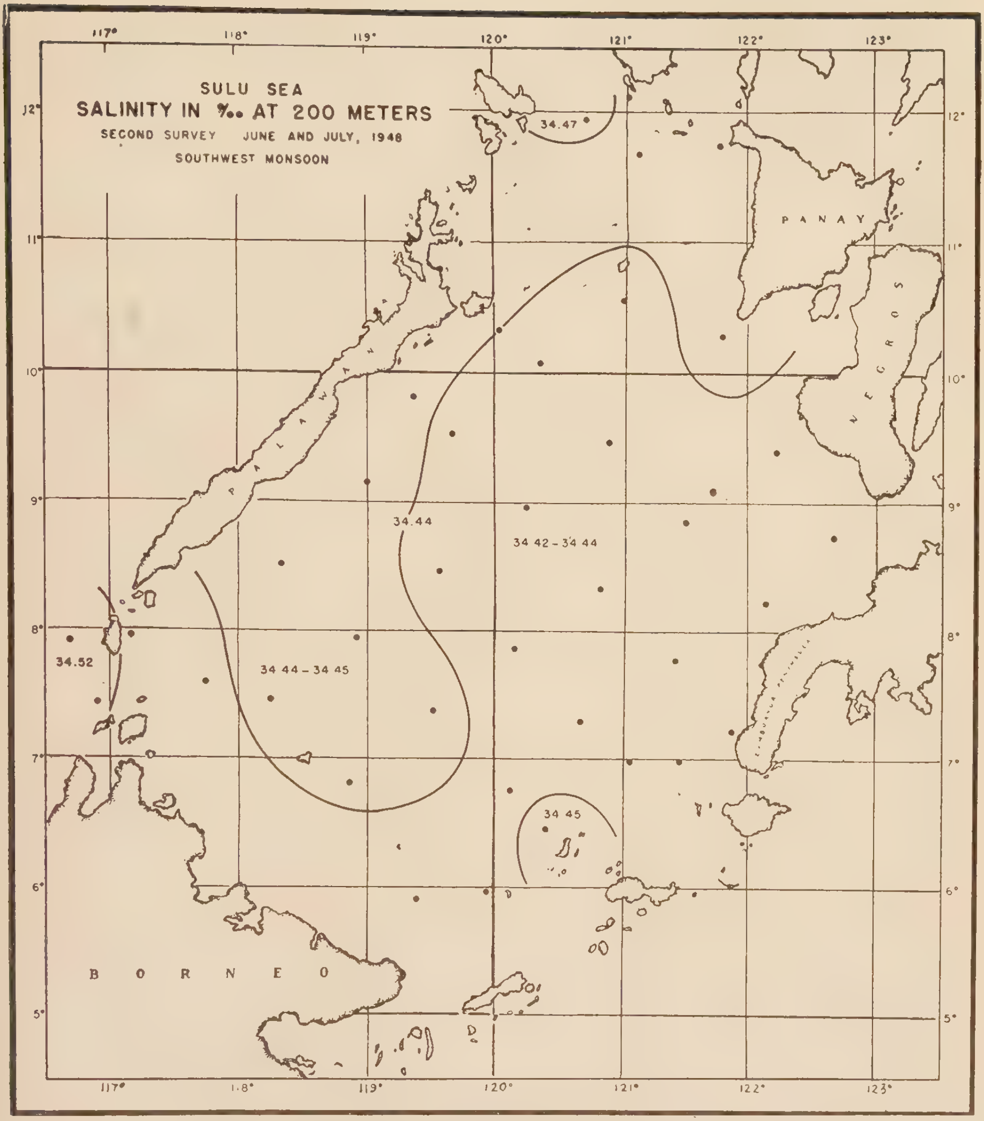

SULU SEA
SALINITY IN ‰ AT 200 METERS
SECOND SURVEY JUNE AND JULY, 1948
SOUTHWEST MONSOON
117°
118°
119°
120°
121°
122°
123°
12°
11°
10°
9°
8°
7°
6°
5°
34.47
PANAY
NEGROS
PALAWAN
34.44
34 42 - 34 44
34.52
34 44 - 34 45
34 45
BORNEO

CHART 27.—Salinity at 200 metres during June and July, 1948

species had been described in the restricted area under discussion. Dr. Hubbs looked forward to the studying of vertebral variation in correlation with the special temperature and pressure combination of the deep sea.

Referring to Dr. Graham's difficulties in making complete hydrodynamic calculations for shallow water areas, Dr. Tully explained a method by which this could be achieved with good approximation to accuracy.

Dr. Hubbs wished to have suggestions as to how any of this data could be used to contribute to increased fisheries catches. Dr. Graham was not prepared to speak to the point, emphasizing only that the work being carried out was basic to all biology to be done in the area. Biologists should be able to make the relevant correlations with the data as it is presented to them.

Dr. Johnson asked whether plankton samples were being secured, what were the main types of fish encountered, and what was known as to their life-histories. The fish concerned mainly were tuna and mackerel, and, regarding plankton, surface hauls only were being made, not below 4–5 ft. from the surface, with half-hour tows. The large zooplankton were principally concerned here. Dr. Johnson concluded by suggesting that attempt be made to get the nets down much deeper. Dr. Graham, in agreeing, briefly pointed out the heavy pressure of work on research trips, and the limited amount that could be undertaken in the short time available to the personnel on board. Dr. Deacon briefly supported Dr. Graham's contention that these physical oceanographical results were basic to fisheries and biology in the area. The data being accumulated was a very necessary foundation.

Some discussion took place on the irregularities in temperature data encountered at a depth of 100 metres. The transition surface was by no means a level one, and no doubt the Spilhaus technique would have revealed more irregularities. A problem for study was the inflow from the China Sea.

Dr. Hiatt further supported Dr. Deacon's remarks on the fisheries aspect. It was desired in the Hawaiian tuna work to have an oceanographic vessel accompany the fisheries vessels to get correlatable physical data. This bulked very important in the ecology of pelagic fishes. Dr. Tully recalled three-year investigation in which more than fifteen fishermen had been equipped with sample bottles and reversing thermometers, the titrating being, of course, done ashore. The results were examined, and there was no correlation of the catch with the moon phase, the temperature, or the salinity. Only the "hours fished" showed correlation with catches—*i.e.*, "the man who had his line in the water caught the fish." It was not yet justifiable to assume that hydrographic data will ultimately give a reliable indication of where fish are likely to be. Dr. Graham believed that we would ultimately find correlation between oceanographical data and the movements and presence of tuna. Temperature stratification influenced the phytoplankton, which in turn influenced the food-cycle of the plankton leading upward to the food of the tuna. In short phytoplankton is the link between physical oceanography and fisheries predictions.

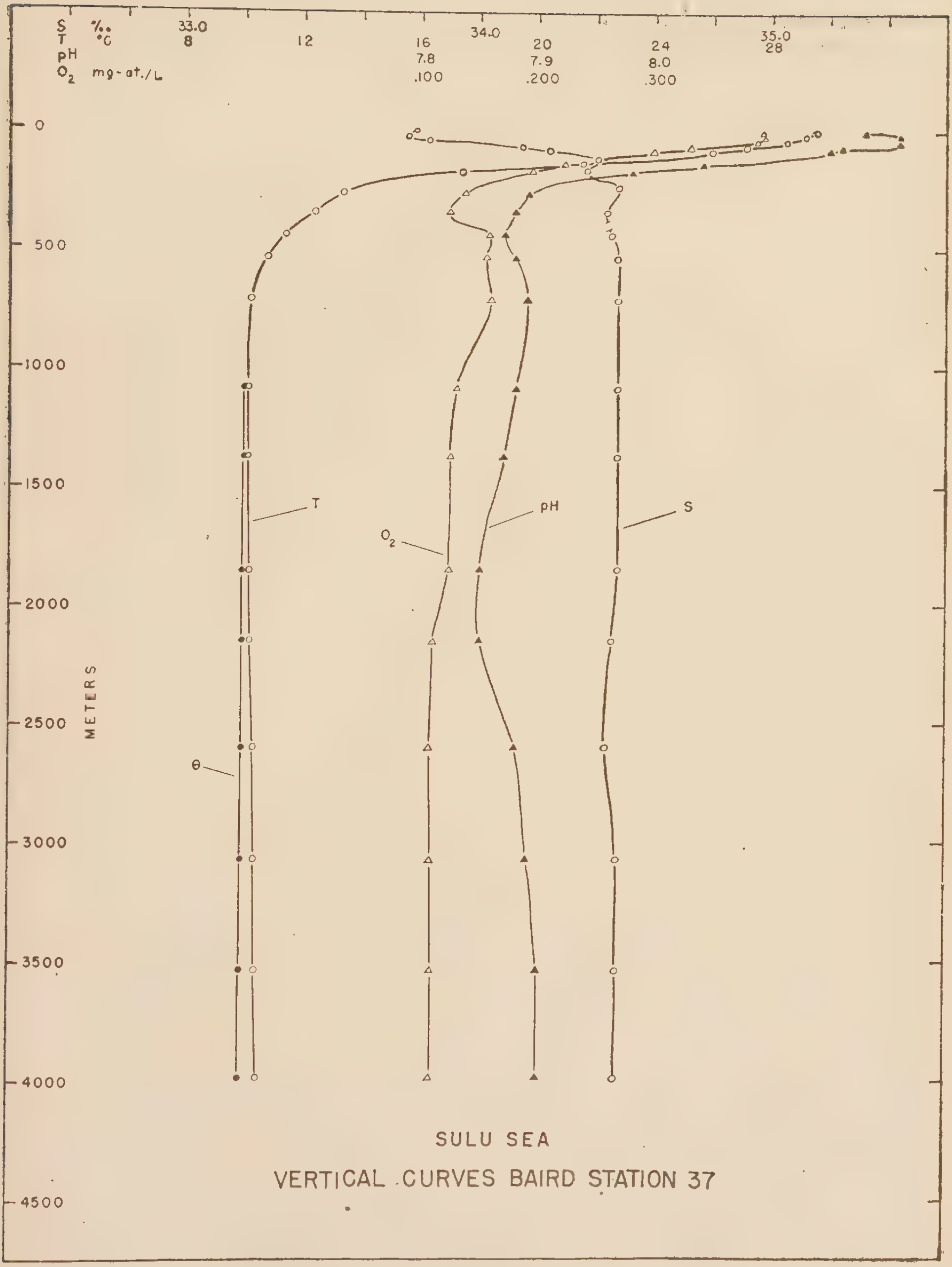


Fig. 1.—Vertical curves of temperature, potential temperature, salinity, oxygen, and pH for Baird Station 37. Latitude 08° 32′ N., longitude 121° 48·5′ E. Values for salinity above 400 metres are taken from Station 36. Latitude 09° 08′ N., longitude 121° 14′ E.

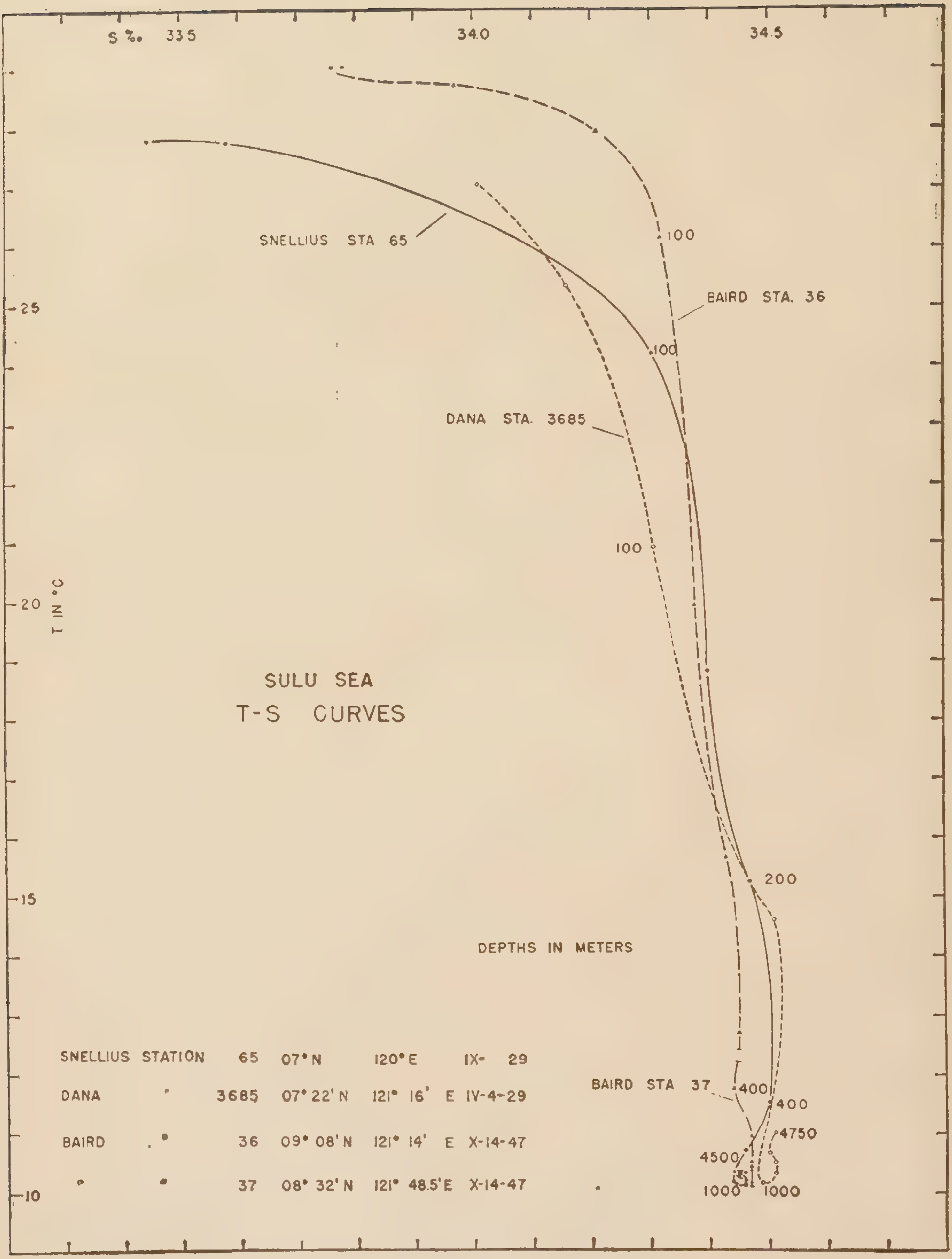


Fig. 2—Temperature-Salinity curves for "Baird," "Snellius," and "Dana" stations

NOTES ON THE BEHAVIOUR OF FRESH WATER ENTERING THE SEA

By John P. Tully, Pacific Oceanographic Group, Nanaimo, B.C., Canada

It has been observed(1, 2, 3, 4) that fresh water flowing into the sea from any river forms a layer of brackish water flowing on the normal sea-water of the region (Fig. 1).

In the upper zone of fresh-water influence the salinity increases to seaward, and with depth to an inflexion in the salinity-depth relation. The upper zone of fresh-water influence is characterized by horizontal and vertical salinity gradients that are large compared to those in the underlying normal sea-water in the lower zone or beyond the influence of the river.

In general the fresh water from the land drainage first overruns the sea-water in the river estuary where the divergence and course of the outflow is determined by the shores. Such a situation is oceanographically simple because the flow is either seaward or shoreward, depending on the tide, and there is only one source of sea-water and one of fresh water. Such systems are exemplified by estuaries, sunken river valleys, fiords, and narrow inlets(1).

When the outflow reaches the ocean, or a large seaway where it is not confined by the shore-line, the situation becomes complex because the direction of flow may vary with time, the tidal movements are not simply reversing, and there may be several sources of fresh and sea-water in any region. Complex structures and tide rips are usually found in such places.

In any case fresh water is continuously supplied from land drainage, and does not accumulate indefinitely. Therefore it is persistently displaced seaward at a rate equal to its supply. The water near the river-mouth is less dense than that to seaward. Consequently, according to Bjerknes, the gradient (solenoidal) effect tends to increase the circulation such that the surface water is accelerated seaward, and the deeper water shoreward. Since circulation of this type is present, but does not increase indefinitely, the gradient effect is balanced by the inertial (Coriolian) effect and friction. This results in the so-called gradient flow along the isobars, but does not define the displacement of water across the isobars from higher to lower pressure. However, such a flow does occur, as evidenced by the mixing of fresh and sea-water. For convenience the component of the pressure gradient which is not balanced by the Coriolian force, and results in trans-isobaric flow, may be termed the displacement head.

Evidently the effect of the Coriolian and the displacement forces must exist in any instance of flow involving fresh and sea water. In an open seaway or the ocean, where the boundaries are not restrictive, the gradient flow is large compared to displacement across the isobars, but in a simple channel the latter is the only mechanism by which stationary conditions may be maintained.

The isostatic forces could be evaluated from suitable data by simple calculations. However, the definition of a horizontal isobaric surface required for reference presents considerable difficulty, since the magnitude of the frictional forces in coastal regions cannot be accurately assessed at the present time. Furthermore, the presumption of a constant circulation over a short period of time cannot be assumed, because the continually varying tidal and run-off conditions make it doubtful if a stationary state is ever observed in a single survey. In general it has been found most satisfactory to seek the relation between the oceanographic state and the primary factors of tide, run-off, and wind by direct observation.

SALINITY STRUCTURE

In coastal regions the density structure is to a large extent a function of the salinity structure alone, the variations due to temperature differences being relatively small compared to the range of salinity involved. Then the fresh water may be regarded as a tracer solution, which may be detected by the degree of dilution with sea-water. This approach offers considerable observational advantage since the only data required are geography, tide, run-off, wind, and observations of the salinity at suitable positions and times, in relation to these factors. All other attributes such as temperature, dissolved oxygen, &c., may be regarded as properties of the mixing waters, or effects of extraneous functions, such as insolation.

Examination of a large number of vertical salinity gradients indicated that they were logarithmic (or inverse square) functions of depth (1, 2, 3, 4), each zone being marked by a continuous relation and separated from the next by a discontinuity in the curve. Heretofore this relation has been open to question because observations were always made at discreet intervals of depth with water-sampling bottles. Recently it has been possible to examine the phenomenon with a salinity-temperature-depth recorder(5), which provides a continuous record. Typical data(3) are shown on natural and logarithmic depth scales in Fig. 2.

The reasons for this mass distribution have not been satisfactorily analysed, but it appears that if the rate of mixing were constant in each zone, this form of curve would result. This would imply that all mixing functions combine within certain depth limitations to provide uniform vertical transfer. Regardless of the explanation, the universal nature of the phenomenon argues for the reliability of interpreting the salinity-depth curves as shown in the figures.

It has been observed(1, 2, 3) that the structure at any position in the zones of fresh-water influence is a function of tide, wind, and river discharge—that is, the structure recurs under like conditions and is not in general a function of time. It is well to remark that, in view of the cyclic nature of the tide, the unit of time is the tidal day.

THE SIMPLE OUTFLOW

In a simple channel (Fig. 1) the flow is essentially two-dimensional. The transport is seaward in the upper zone, and below this sea-water may enter and leave on the tidal cycle imparting a reversing component to the system. The direction of flow is defined by the geography of the channel.

Evidently three mechanisms are involved in such a system—the seaward movement of fresh water in the upper zone due to its displacement head, the reciprocal movement in the upper and lower zones due to the hydraulic head of the tide, and the mixing of the two waters.

Tide

During the ebbing tide sea-level falls and the tendency for water to leave the channel because of this hydraulic head is the same at all levels, but is accelerated in the upper zone by the displacement flow.

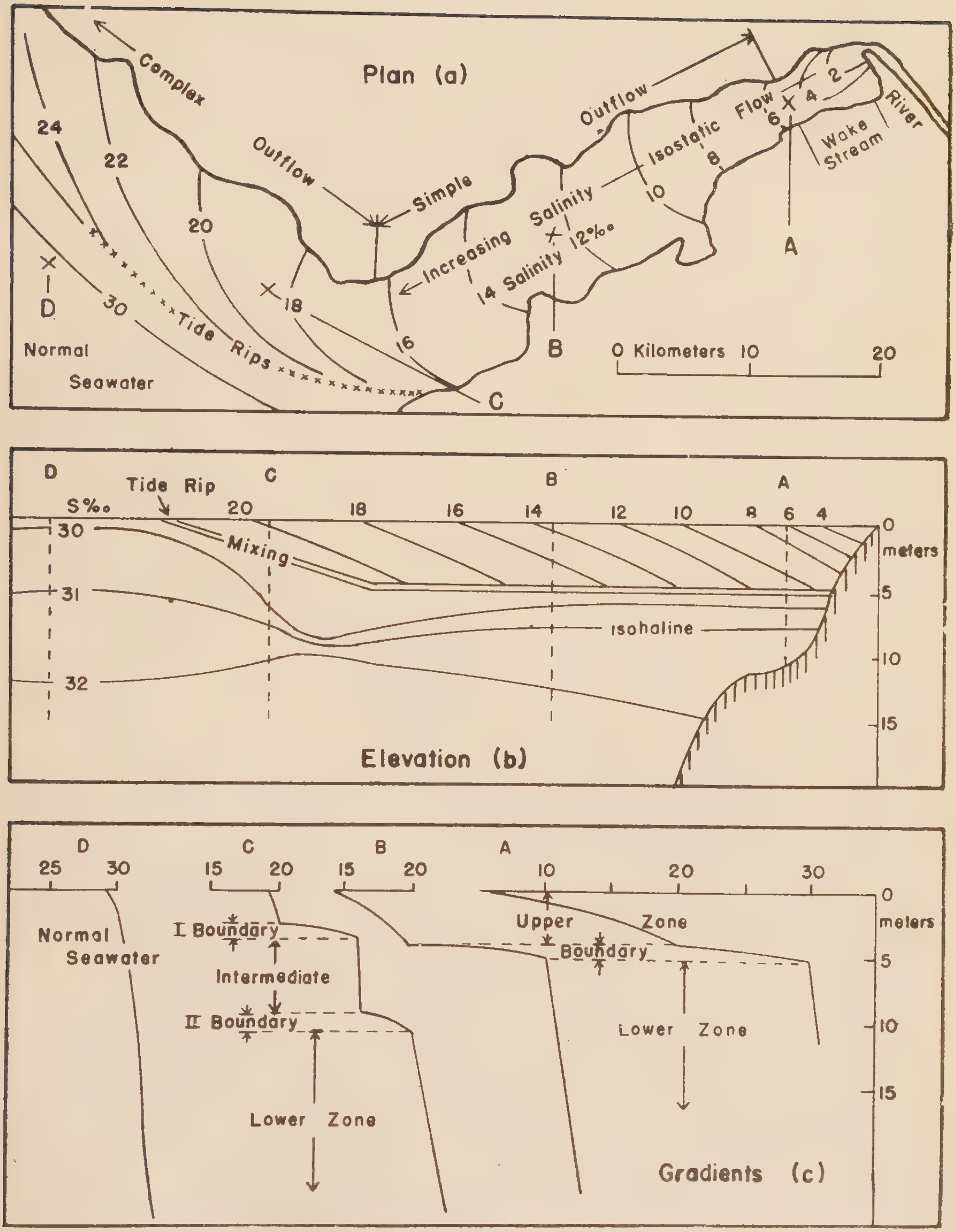

Plan (a)
Complex
Outflow
Simple
Outflow
Isostatic Flow
River
Wake Stream
Increasing Salinity
14 Salinity 12‰
24
22
20
18
16
30
10
8
6
4
2
A
B
C
D
Normal Seawater
Tide Rips
0 Kilometers 10 20
D
Tide Rip
C
B
A
S‰
20
18
16
14
12
10
8
6
4
30
31
32
Mixing
isohaline
0 meters
5
10
15
Elevation (b)
D
C
B
A
25 30
15 20
15 20
10 20 30
Normal Seawater
I Boundary
Intermediate
II Boundary
Lower Zone
Upper Zone
Boundary
Lower Zone
0 meters
5
10
15
Gradients (c)

FIG. 1.—Diagrammatic illustration of salinity structure in vicinity of a northern river outflow

At low tide the tidal forces vanish, and the only flow is the seaward transport in the upper zone. As the tide rises the sea-water enters the lower zone, since its density is greater than the upper zone, and creates a flood current, which increases with the rate of tidal rise. The slack water associated with low tide occurs when the opposing tidal and displacement velocities are equal. As the tidal velocity continues to increase, the upper zone is erased to seaward and retreats into the channel. It becomes thicker, and fresh water accumulates, increasing the isostatic forces until they equal the hydraulic forces of the tide. In this situation a front separating the invading sea-water and the upper zone is formed near the mouth of the channel (Fig. 1) which progresses in-shore as the tide rises.

Eventually the isostatic and tidal forces again attain equality, due to increase of the former or decrease of the latter, and a second period of slack water occurs, associated with high tide. Thereafter the surface seaward displacement is resumed, while the flood movement in the lower zone decreases to zero at high tide.

The sea-water entering the lower zone during the flood, less the land drainage, is the volume required to make up the tidal rise. The ebb from both zones consists of the volume required by the fall of the tide, plus the land drainage during this phase.

Then during the steady state the fresh water transferred seaward through any cross-section of the channel during a tide-cycle is equal to the land drainage above the section, and equal volumes of sea-water flood and ebb through the section in a cycle. If these consequences did not obtain, fresh or sea water would accumulate over a series of cycles and the channel would become totally fresh or sea water. Obviously the considerable mixing during the process has no effect on the quantities transferred.

It is implied in this argument that surface sea-water submerges below the upper zone at the front and enters the channel in the lower zone during the flooding tide, some of it is transferred to the upper zone in the channel, and sea-water escapes from the channel by both zones during the ebb tide. It follows that, aside from the fresh water present, the movement of sea-water in the upper zone is biased in the ebb direction, while that in the lower zone is biased in the flood direction, in compensation for the sea-water transferred upwards.

Turbulence

The progressive increase of salinity in the upper zone must be the result of some mechanism of turbulence. Turbulent flow is usually exemplified in Nature by a large number of more or less coherent eddies having random compensatory motion within the fluid. This motion is opposed by friction between the elements (eddy viscosity) resulting in an exchange of fluid between the eddies and their surroundings (mixing).

In a density stratified medium any movement of the fluid elements within a stratum is opposed by viscosity alone, but any movement of the elements from one stratum to another is also opposed by isostatic forces, which tend to return the element to its own level. From this it would be expected that a stratified system would become more homogeneous down-stream, and that lateral homogeneity would be more readily attained than vertical homogeneity. This reasoning has been confirmed by observation(1) and is indicated in Fig. 1.

Reynold showed that in a wide channel the incidence of turbulence s a function of the average velocity and depth (of homogeneous layer), as shown in Table I.

TABLE I—REYNOLD NUMBER

Flow is turbulent when—

$$N_R = \frac{VD\rho}{v} = 500$$

N_R Reynold number.
V mean horizontal velocity.
D depth of channel.
ρ density of fluid.
v kinematic viscosity.

Velocity cm./sec.	Depth. cms.
7·65	3·05
1·53	15·25
0·77	30·5
0·15	152·5

In the vicinity of an estuary the mixing between fresh and sea-water zones must be attributed to external forces such as the wind and tide, because the isostatic flow is in general less than the threshold of turbulence as defined in Reynold's experiments. Examining the discharge of several rivers(1, 2, 3) it became evident that the flow due to the dispersal of fresh water alone would cease to be turbulent at a short distance from the outfall because of the widening front of flow in the sea.

The tidal velocities in most coastal regions are adequate to cause a considerable degree of turbulence, and because they are rotary or reversing their contribution to transport is small. In open seaways mixing due to the acceleration of the wind must also be considered, and may be assumed to be the predominant factor in the ocean, where tidal movements are small.

Obviously some degree of mixing would result from isostatic movements, but in general the mixing function is superimposed on the isostatic flow functions by extraneous forces. It is concluded that in a simple channel mixing occurs primarily at the expense of the tidal rise and fall, while the seaward transport of the water is due to the displacement head.

This was confirmed by observation in Alberni Inlet(1) where the tidal velocities attained 150 cm./secs., but the rate of net transport seaward was of the order of 0·01 to 0·06 cm./sec.

It is evident that an isostatic movement would occur whether or not there was mixing. Therefore the seaward movement of fresh water is not consequent on the rate of mixing. However, it is implied that the fresh water must move seaward at a rate equal to its supply, wherefore the stream must accelerate or diverge in proportion to its dilution with sea-water. This agrees with observations(1) which show that the velocity and mass transport in the upper zone of such systems increases to seaward, and that the dimensions of the zone is constant within certain limits of variation.

Mixing

In general, the upper and lower zone both become more saline to seaward, from which it is reasoned that all the fresh water is dispersed in the upper zone, and little or no fresh water is lost by downwards transfer. This requires some explanation, since in any process of mixing the volume of water transferred downwards must equal the volume transferred upward, else the medium would become discontinuous.

In the case of an upper zone carrying fresh water over a lower sea-water zone which moves in the same direction with the same or greater velocity, the exchanged water would be carried forward in both zones, the upper zone becoming more saline and the lower zone less saline as they approach homogeneity. However, this process would imply that the upper zone flow was in the opposite direction and of lesser magnitude than the movements in the lower zone. It does occur near the front at the mouth of the inlet and results in modifications of the simple system, which will be discussed later under " Complex Outflows."

It is more usual to find the lower sea-water zone moving in an opposing direction relative to the upper zone, in which case both layers become more saline to seaward. The sea-water transferred upwards is carried forward with increased velocity to be exchanged for more saline water down-stream. The upper-zone water transferred downwards will lag behind the surface flow, or be carried backwards in a boundary zone, in which there is a transition between the salinity of the lower and upper zones, and be preferentially subject to further mixing into the upper zone. Any fresh water accumulating in the lower zone would be isostatically unstable and would tend to join with the upper zone in the boundary layer.

The nature of the mixing process is indicated by the vertical salinity gradients. It may be assumed that there is a compensatory exchange of water across the boundary, and then to the adjacent parts of the zones. If the mixing at the boundary were more rapid than the mixing in the adjacent parts of the zones, mixed water would accumulate, and a homogeneous boundary layer would be created, as shown in Fig. 3 (*a*). This may be observed in the vicinity of a front, as will be discussed later. It is unstable since it implies a large turbulence function confined to the boundary, and normally such a function also includes the upper zone.

If the rate of mixing in the boundary equalled the rate of mixing adjacent to the boundary, the boundary zone would lose its identity in the formation of a simple gradient from the surface to the lower zone as shown in Fig. 3 (*b*). This is occasionally observed in Nature when the stability of the boundary zone becomes small.

Finally, if the mixing adjacent to the boundary were more rapid than the mixing in the boundary, the salinity gradient would be expected to be a maximum in the boundary which would be a distinct zone, as shown in Fig. 3 (*c*). This is the form of gradient commonly observed in simple situations(1, 2, 3).

The structure consequent on these processes is illustrated in Fig. 4 (*a*), where a representative series of salinity gradients are shown in relation to their position in the simple channel of Alberni Inlet(1). Figure (4) (*b*) shows the same gradients plotted on a logarithmic depth scale and superimposed on each other.

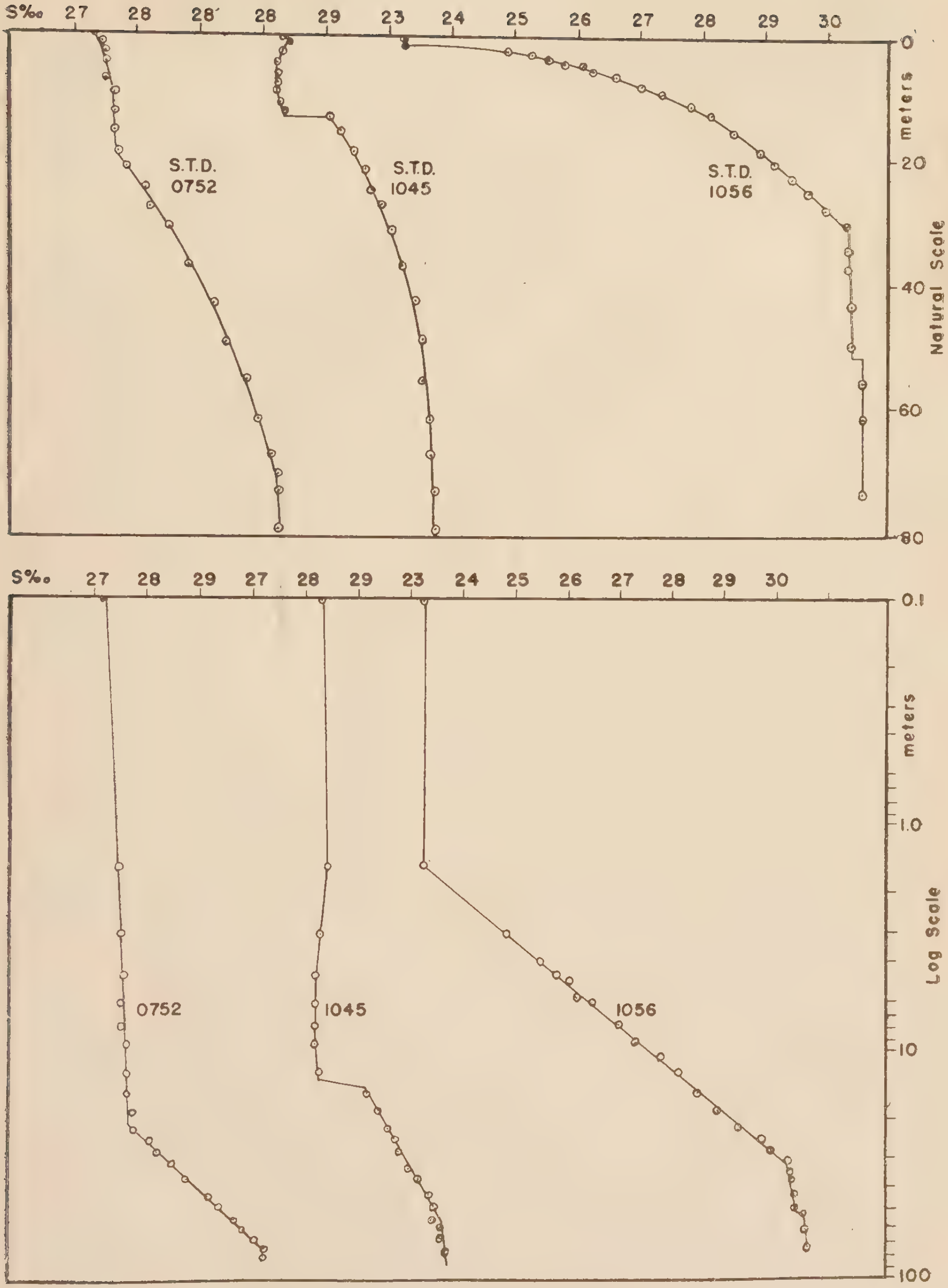


FIG. 2.—Salinity data from Georgia Strait Survey 8th December, 1948

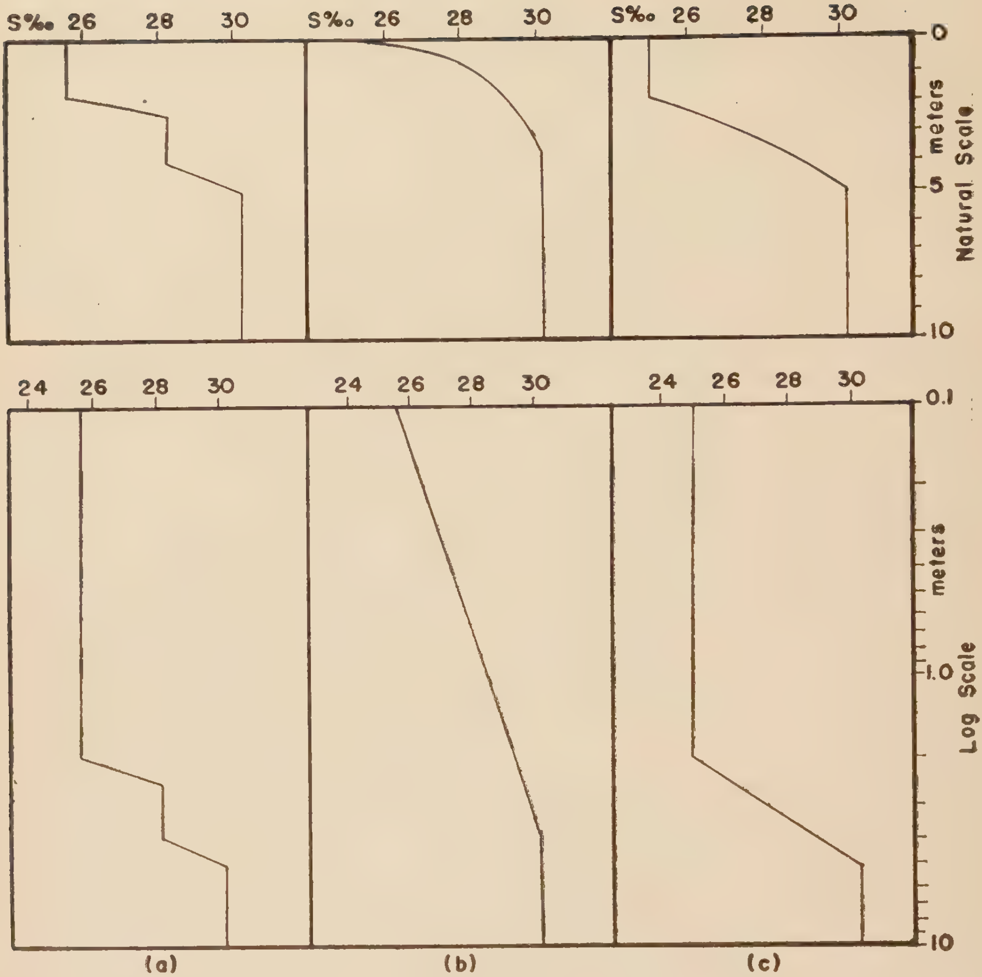


FIG. 3.—Idealized vertical salinity gradients showing type boundaries

The upper and boundary zones become progressively more saline to seaward as they degenerate to obscurity. Evidently sea-water is being transferred upwards and retained in the upper zone, and no fresh water is being transferred below the boundary. This identifies the boundary as the zone into which fresh water is transferred in the mixing process, and from which it is preferentially returned to the upper zone, along with the associated sea-water supplied from the lower zone.

From this it may be concluded that all fresh water leaves the region by way of the upper zone, and that the fresh-water influence is finally lost by infinite dilution with sea-water, when the upper zone becomes indistinguishable from the lower zone.

Evidently the upper zone is subject to two accelerations—the displacement of fresh water, which is constant through any complete cross section, and the transfer of sea-water from the lower zone. The

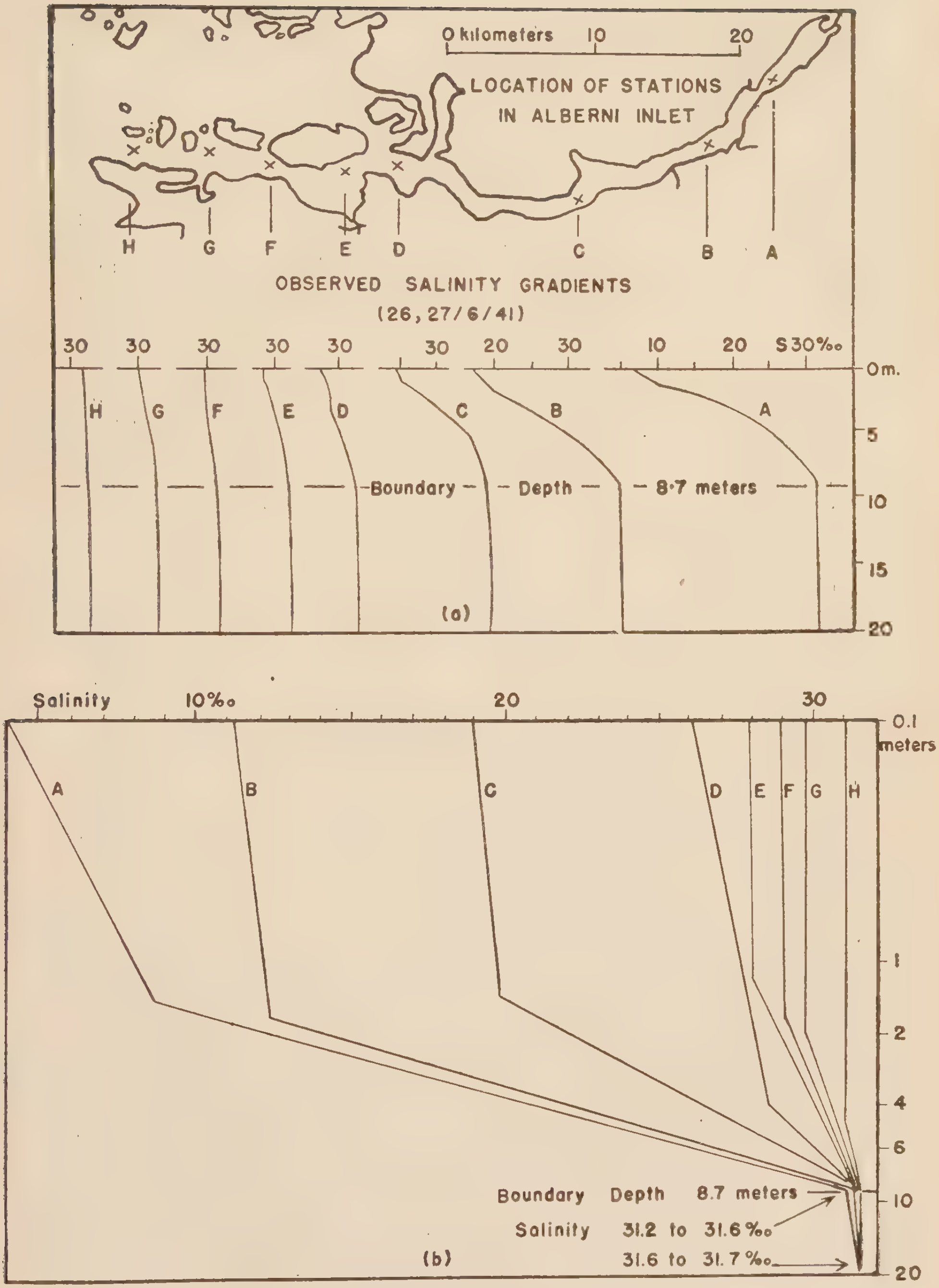


FIG. 4.—Salinity gradients, logarithmic depth scale

latter accumulates in the upper zone where the velocity increases to seaward in direct proportion to the increase of sea-water content, and inversely as the cross-section area of the upper zone.

The seaward salinity gradient originates in the turbulence function and is maintained by the displacement flow. The latter is limited to the depth of the boundary, which must therefore be a minimum potential surface and cannot be altered by forces within the system. The upper and boundary zones are everywhere less dense than the lower zone, therefore any change of level will invoke local accelerations to restore the position of minimum potential energy. The difference in level between extremes of this zone in the data cited in Fig. 4 would be of the order of 7 centimetres, which is within the limits of accuracy of the observations.

DISPLACEMENT

From the preceding discussions it may be realized that at equilibrium the fresh-water outflow must be displaced seaward at a rate equal to its supply, therefore it must be possible to evaluate the seaward movements in the upper zone and the degree of mixing in terms of the discharge of the parent river.

Some proportion of the fresh and sea water in any limited region of the upper zone is displaced by like amounts entering the region in a limited time-interval. Evidently the proportion of fresh water displaced is the same as the proportion of sea-water displaced, otherwise one or other of the components would accumulate. Therefore displacement may be quantitatively defined as the proportion of water in any limited region that is replaced by new water in one complete tide-cycle. Displacement may then be evaluated from an analysis of the fresh-water distribution: consider an area (A) in which the depth of the upper zone (D) contains a proportion of fresh water (C), into which the rate of fresh water discharge is (Q) during the time of a tide-cycle (T). Then the displacement of fresh water (r) is the ratio of the volume of fresh water entering the region (QT) to the volume of fresh water already in the region (A C D)

$$r = \frac{Q\,T}{A\,C\,D}$$

This expression is exact and implies an absolute knowledge of the factors. However, when observing the natural state it is usually necessary to make interpolations and approximations in the values.

The depth of the upper zone may be determined as the intercept of the lower and boundary gradients (Fig. 4). The proportion of fresh water in the region is the ratio of the area bounded by the salinity curve, the surface, and the salinity ordinate intercepting the point defining the depth of the boundary, to the product of this salinity and depth. These quantities may be interpolated with reasonable accuracy from suitable salinity observations, and usually the runoff may be observed directly. Therefore the equation can be solved in any region where the boundaries can be defined.

RELATION TO RUNOFF

The relations of these quantities to the discharge of the parent stream are shown in Fig. 5, from the studies in the simple system in Alberni Inlet(1).

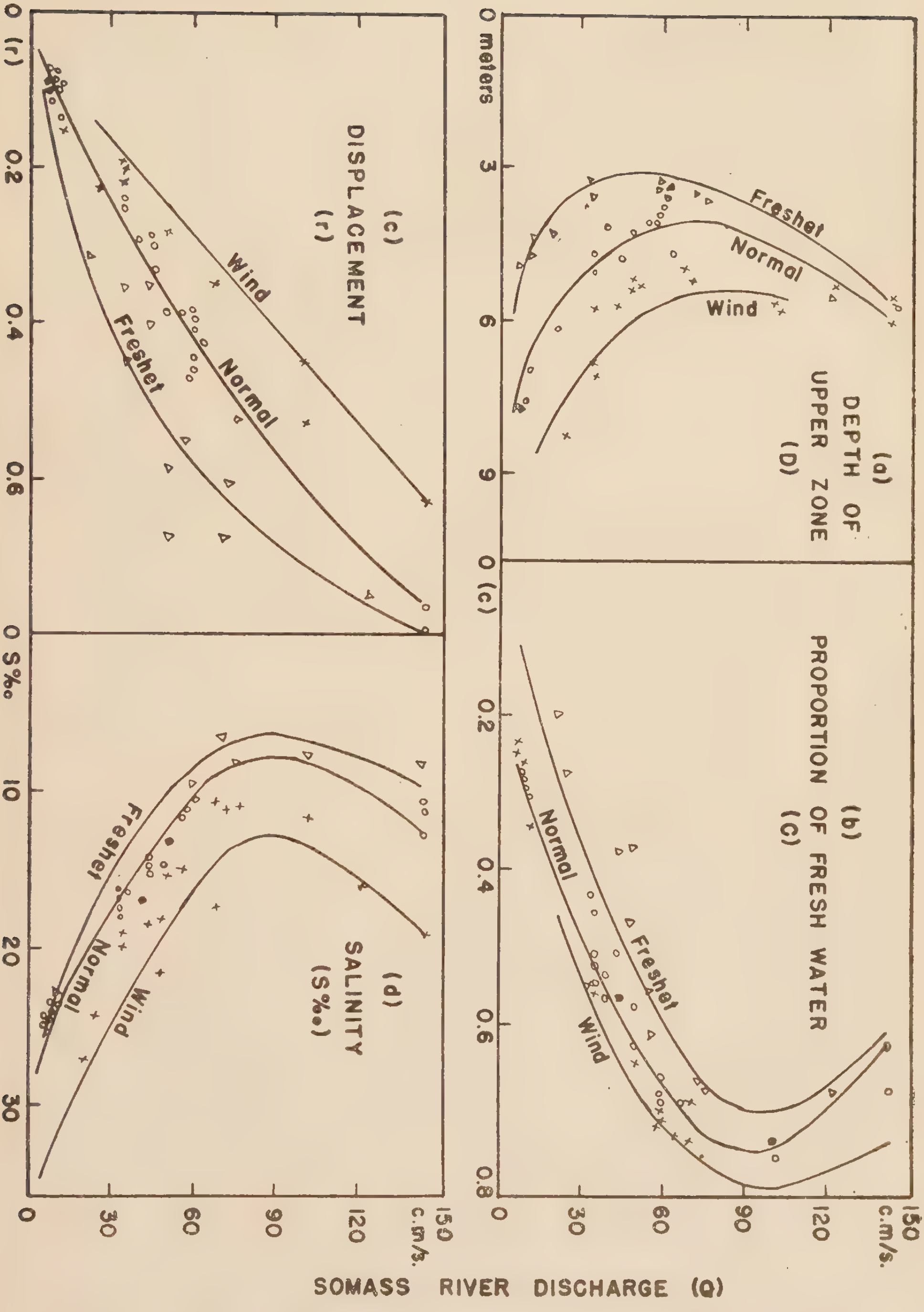


FIG. 5.—Properties of the Upper Zone in Alberni Harbour related to Somass River Discharge

△ Freshet divergence.
○ Normal relation.
× Wind divergence.

It was found that the points were considerably more scattered from a simple relation than would be expected from variations in tidal height. The deviations in one direction were associated with increasing run-off and were designated as freshet deviation. Deviations in the other direction were associated with strong winds opposing the seaward direction of surface flow, and were referred to as wind deviation. The best line drawn through points representing steady run-off, or falling river-level, and light winds was taken to represent the normal state.

The form of the curves are remarkable. Evidently from low to intermediate discharge level, the upper zone becomes shallower and fresher, while at greater discharge it becomes deeper and more saline, although the displacement increases almost linearly. These phenomena may be interpreted with the aid of salinity gradients shown in Fig. 6 (*a*) observed during the low, intermediate, and high river discharge at a position near the head of the inlet. When land drainage is small the displacement is necessarily small, and the upper-zone water remains in the region for a considerable time so that a deep, saline upper zone is formed, as shown in the first gradient of Fig. 6 (*a*). As the run-off increases displacement increases, and the time during which the upper zone is exposed to tidal mixing in the region decreases. In consequence it becomes shallower and fresher, as indicated in the second gradient. Further increase of river discharge implies that the front between the fresh water impounded in the channel and the intruding sea-water must move further seaward. This requires increased isostatic forces, wherefore the upper zone must remain fresh and become deeper, as shown in the third gradient. This case implies considerable transport velocity, with consequent turbulence, so that the boundary gradient is thicker than in the previous case, and since it is included in the assessment of the upper zone, the salinity appears to increase.

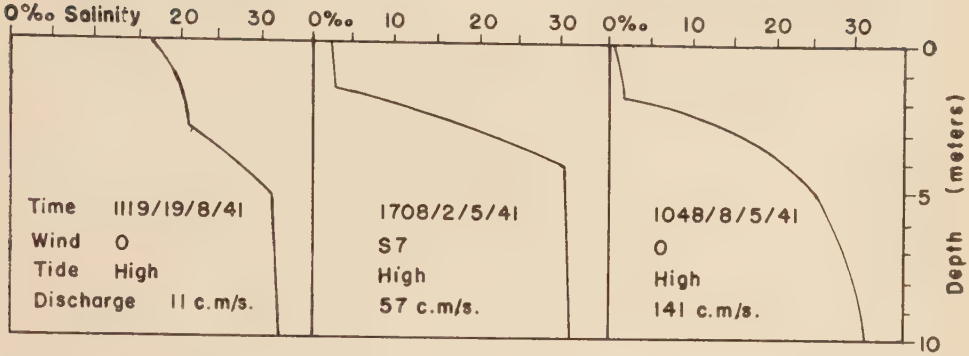
WIND EFFECTS

When the surface seaward flow is opposed by strong winds it would be expected that the depth of the upper zone would become greater than normal, because of the increased mixing forces, and fresh water would accumulate until the isostatic head was great enough to provide normal displacement against the restriction of the wind. This is illustrated in the sequence of group (*b*) gradients in Fig. 6. It is shown in Fig. 5 that the effect of the wind is greater when the depth of the upper zone is the least. The accumulation of fresh water in the region is shown to increase with the run-off. The effect on displacement increases to a limiting value as the boundary approaches a minimum depth, with intermediate discharge, and the surface waters are freshest. The limit is reached when the depth of the upper zone becomes great enough to permit displacement in the upper zone, below the level of wind influence.

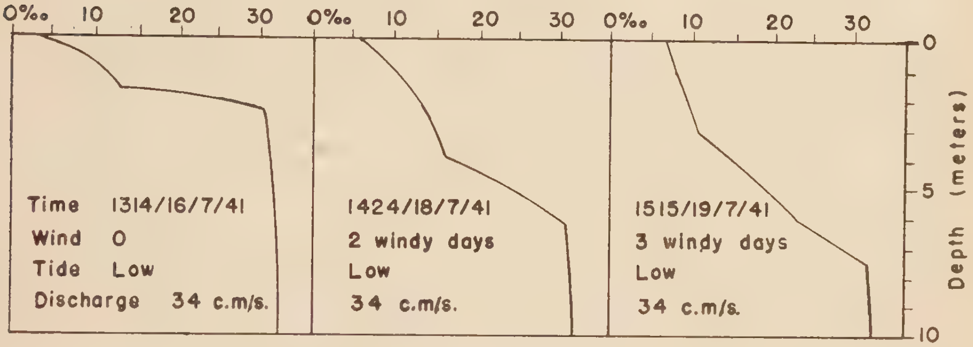
Freshet Effects

It is apparent that the displacement must increase with run-off, but the evidence that the depth of the upper zone decreases is enlightening. This is illustrated by the sequence of gradients shown in Fig. 6 (*c*).

(a) Equilibrium at different discharge levels.



(b) Effect of Wind



(c) Effect of Freshet

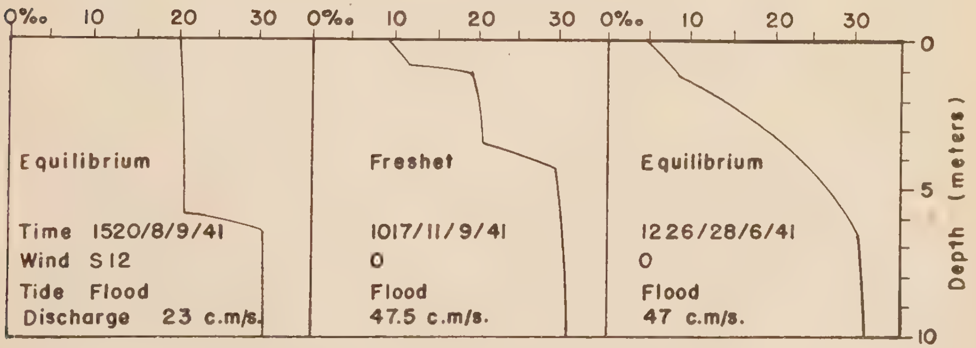


FIG. 6.—Salinity gradients in Alberni Inlet

As the displacement increases the freshet overruns the surface, repeating within the upper zone the phenomenon of the upper zone in the sea. This is shown by the transition from the first to the second gradient. If the rise is a true freshet, of short duration, the process ends there, and the original state is slowly re-established. However, if the higher discharge continues at a constant level fresh water accumulates until a new equilibrium is established, as indicated in the third gradient, and the boundary finds a new level.

It is concluded that a freshet has the effect of flushing the channel, and produces anomalous values of depth and salinity, since it does not represent stationary conditions.

Dynamic Equilibrium

It may be concluded from these discussions that the salinity structure is recurrent within the limits of variation of wind and run-off at corresponding states of the tide-cycle. It might better be regarded as a probability, whose deviation from the normal or median state depends on the wind and run-off history immediately before the observation.

The fresh-water content of the upper zone represents the accumulation of fresh water required to provide the isostatic head necessary for the continuous displacement of fresh water at a rate equal to its outflow from the river. Evidently this can be accomplished in a shallow, very fresh zone, or a deeper, more saline zone, depending on the magnitude and time of action of the extraneous mixing forces of the tide, and the wind.

THE COMPLEX OUTFLOW

The coastal seas are subject to tidal currents(7) which are more or less rotary, so that there is no period of slack water, and there is a shoreward or seaward component of flow as the tide rises or falls.

As the outflow moves seaward, whether it be radially off-shore or coastwise it will encounter an opposing tidal current on some margin, and a front will be formed wherever the movements converge.

This phenomenon is illustrated diagrammatically in Fig. 7. The fresher outflow overruns the adjacent sea-water, and forms a frontal surface which intercepts the sea surface. This frontal surface is maintained by convergence towards, and a compensatory flow along, it. At the " front " (the intercept of the boundary with the sea surface) the horizontal convergence is balanced by a compensating vertical flow along the boundary surface. This flow consists of water contributed by both masses in proportion to the horizontal velocities normal to the front. The upper zone of the outflow may move faster than the adjacent sea-water at the surface, and so contribute more water at that level, but generally the normal velocities decrease downwards in the fresh-water mass more rapidly than in the sea-water mass, and the relative contributions to the boundary may change with depth. The waters contributed by the fresh and sea-water regions are sheared off the front, mixed, and submerge to a position of isostatic stability below the upper zone of the outflow, forming a boundary zone or, in more extreme cases, an intermediate zone between the upper and lower zones.

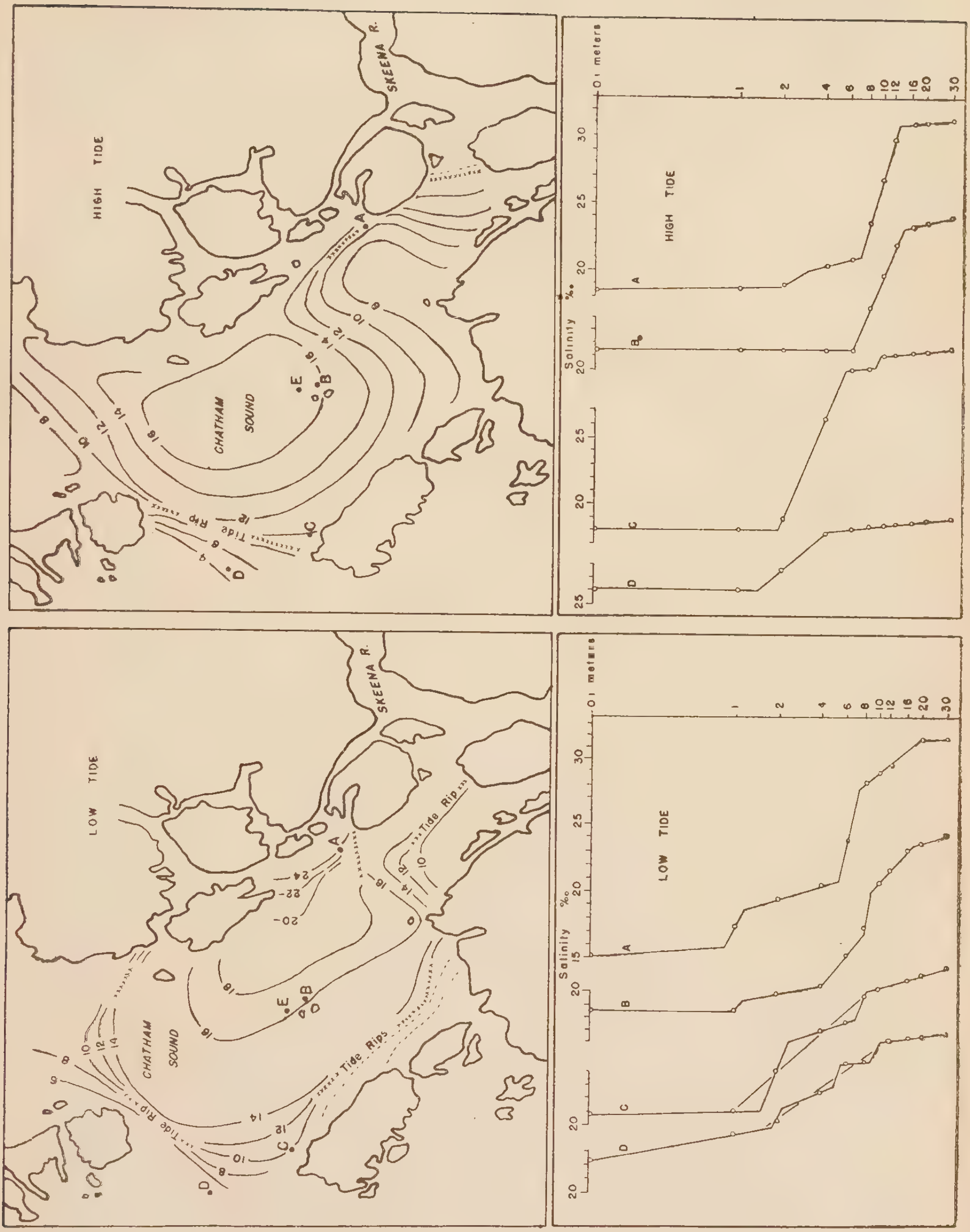

HIGH TIDE
LOW TIDE
SKEENA R.
CHATHAM SOUND
A
B
C
D
E
Tide Rip
Tide Rips
Salinity ‰
0 1 meters
1
2
4
6
8
10
12
16
20
30
15
25

FIG. 7.—*Upper figures :* Concentration of fresh water (per cent.) in the upper 20 metres of Chatham Sound

Lower figures : Salinity gradients observed of lettered positions in Chatham Sound. Observations of 14–18/6/48

The situation is dynamically stable while the front is being continually renewed by a supply of water from both regions, and the mixed waters are being continually dispersed at an equal rate. Its position represents the balance where the acceleration in the tidal and isostatic flows are equal. Such regions of convergence vary from " tide lines " marked by a collection of flotsam, and/or a difference in colour of the water, to violent tide rips which may endanger small ships, depending on the velocities and magnitude of the opposing upper zones.

The synoptic charts of the concentration of fresh water shown in Fig. 7 were compiled from data observed during four days in Chatham Sound, on the Pacific Coast of Canada. The position of the tide rips in relation to the water masses indicates that they represent zones of convergence between flow across the isohalines and opposing movements in the more saline water from the adjacent sea. The salinity gradients associated with this structure were observed to be complex in almost every case, as indicated in those illustrated.

The Intermediate Zone

It is anticipated, and observations appear to show(3), that the intermediate zone associated with a front (Fig. 1 (*c*)) is usually of moderate dimensions and restricted to the vicinity of the front, because it is essentially a transitory state in the formation of a new boundary zone. The intermediate zone is evident because the mixing process at the front is proceeding faster than in the adjacent parts of the upper and lower zone, and mixed water accumulates in the boundary. This process has been illustrated in Fig. 3 (*a*) and associated discussions. As the intermediate zone is removed from the front it tends to contribute to the upper zone, and forms a simple boundary, usually at a new depth. It is implied that this metamorphosis is associated with considerable movement which is continuous with the convergence at the surface front, and has a large component parallel to it. This situation corresponds to the high tide gradients shown in Fig. 7.

The intermediate zone may also be generated when the river outflow overruns a previous discharge, which meanwhile has been considerably diluted with sea-water. This is the situation illustrated in the low-tide gradients of Fig. 7. It has been remarked that this is particularly noticeable during a freshet. It also occurs in the vicinity of a river-mouth, because of the oscillatory nature of the tide. By a combination of these functions as many as three intermediate zones have been noted(2). but it is remarked that they tend to approximate the structure of a simple boundary in which the salinity gradient is a logarithmic function of depth. These multiple intermediate zones usually occur in protected sounds or bays where the waters may be confined for some time before reaching the open sea. The data illustrated represents this combination of circumstances.

Evidently the fate of the intermediate zone in the vicinity of the outflow is to become identified with a simple boundary structure.

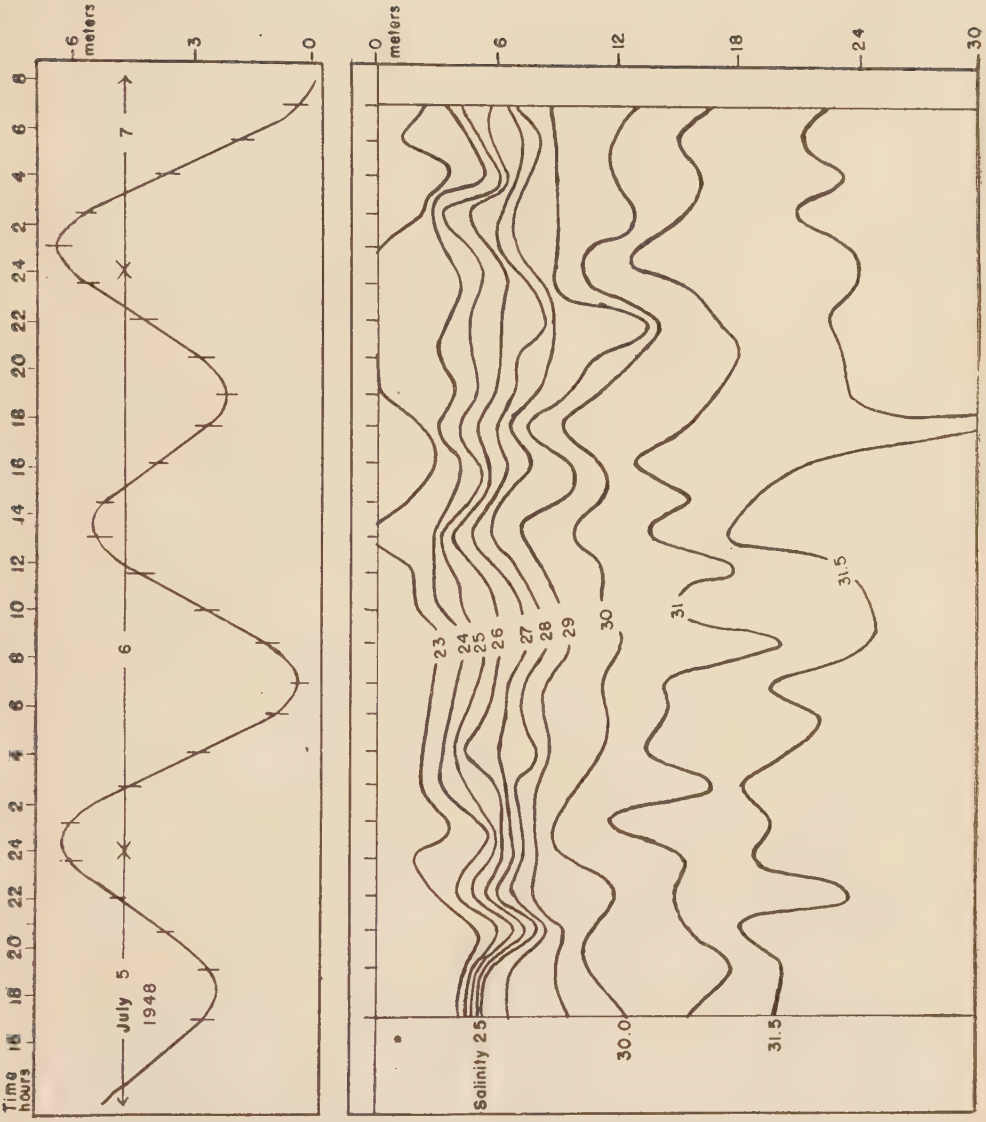


FIG. 8.—Synopsis of salinity-time profile taken at a position in an open seaway in the region of influence of a large river Position E in Fig. 7

Discontinuous Outflow

Both the character and volume of the outflow vary with the tide. When the tide is falling, the upper zone has free egress from the estuary to the sea, since the flow in the lower zone is also seaward. During this tidal phase the upper zone tends to move rapidly away from the estuary, in a balance of gradient and displacement flow, modified by the tidal currents in the vicinity, as shown by the low tide distribution of fresh water in Fig. 7.

In the presence of rotary tides the direction of the stream may be seen to alter from time to time during the discharge. Usually it will flow in one direction for a time, and then change direction at the source quite suddenly, leaving a cloud of upper zone water isolated in the seaway.

When the tide rises sea-water usually invades the estuary, forming a front near the channel mouth, as has been described. Usually the upper-zone water discharged during the ebb has been removed from the vicinity by the local current systems, so that sea-water intrudes the estuary. This movement has the effect of cutting off the upper-zone water extruded during the previous ebb, which then floats away as a cloud. This mechanism is indicated in the high tide synoptic of Fig. 7.

When separated from their source these clouds of upper-zone water lack the isostatic forces to continue their flow and are pelagic in the surface of the seaway, where it is common to observe considerable variations of current and direction in short distances. In some circumstances the successive upper zone clouds may follow quite different courses(2). When this phenomenon is observed in the usual manner by water sampling at intervals of distance it may appear that the flow from the estuary is forked, whereas a truer interpretation would be that clouds of water are discharged alternately in the several directions.

Evidently these clouds will tend to expand radially over the sea surface under the influence of their own isostatic potential. In this case they should tend to rotate, because of the Coriolian force, and should be deepest at the centre. The formation and existence of these clouds of discharged water have been observed(9), but to present knowledge they have not been studied.

In the immediate vicinity of the outflow into a large seaway or the ocean it has been observed(2, 3, 6) that the upper-zone flow tends to follow the course that would be anticipated from dynamic topography of the sea surface. However, the upper zone appears to contain clouds of fresher water, corresponding to the discharge during successive tidal periods, since the depth and composition of the upper zone fluctuates along the line of flow. In general, the system tends to become more saline and regular with distance from the parent river.

In the simple system(1) the anticipated variation of depth of the upper zone with the tide was observed. However, in a complex system(2) the tidal variation was completely masked by a secondary variation of equal magnitude, as illustrated in Fig. 8. This apparently random variation could be explained by internal waves or by the discontinuous nature of the outflow, or possibly both. Associated data indicates that the boundary layer did oscillate in short periods, and that a cloud structure was present. This is indicated in the charts of Fig. 7, and probably explains the large variations in depth of the boundary shown in the corresponding salinity gradients.

It is apparent that the diverging outflow into a large seaway is not continuous and that any static representation can only imply an average state, about which the natural state varies. The present oceanographic instrumentation is not adequate to follow these short-period variations, even the salinity-temperature-depth recorder(5) will require some improvement before this is possible. At present it is necessary to make a series of observations at small intervals of time until enough data is collected to evaluate a reliable statistical mean of the structure. The additional time required almost vitiates the possibility of making a synoptic survey of an extensive area, where functions of tide, wind, and run-off must also be considered. It is probable that the only satisfactory approach to this problem is by model studies. A model of Alberni Harbour(11) was made in which the geography, tide, and river discharge were simulated and was successful in reproducing all the features of the outflow which have been discussed. This indicates a practical approach to the study of seaways where the boundary conditions can be represented.

THE OCEAN OUTFLOW

When the outflow enters a large seaway or ocean it tends to form a jet stream(10) which veers to the right or left in response to the Coriolian force(11), at least in the middle and polar latitudes, and moves coastwise, contrary to the great ocean currents. This is more of a gradient flow along the isobars than a displacement flow across the isohalines.

Figure 9 shows an interpretation of the dynamic topography off the Pacific Coast of Canada(8) which may be regarded as representative, since the illustrated coastal current has been observed empirically, and qualitatively related with the local seasonal run-off(7) and the Japan current off-shore corresponds with what is known of this movement from casual and experimental drift observations(12).

Evidence of cloud structure in the surface waters of the open sea have been observed(14), but in general the fluctuations in properties of the water are small compared to those in the immediate vicinity of an outflow. In general, the shallow and irregular upper zones tend to obscurity in short distances because of the accelerated mixing by the considerable wind forces. Once this simplification has taken place the structure appears to be very stable and to degrade along the line of flow by a somewhat similar process to that observed in the simple system.

This is illustrated in Fig. 10, which shows a series of salinity gradients observed at regular intervals through 180 kilometres off the Pacific Coast of Canada. These stations correspond to the numbered positions in Fig. 9. They were observed while proceeding seaward on 20th July, 1936, and again during the return journey the next day, and both data are indicated in the figure.

The lower boundary is taken to mark the effective depth of wind mixing along the course of the Japan current in the open ocean, and the intermediate layer to represent the character of this water. The upper zone is shown to be continuous with the coastal system and represents the influence of local fresh water in the great ocean current.

This also implies a transfer of water across the isobars—that is, there is a component of flow normal to the isohalines, corresponding to the displacement flow of the simple system. Evidently both the gradient and displacement tendencies must continue to exist at all times. In the two-dimensional channel the gradient flow is limited by the boundaries

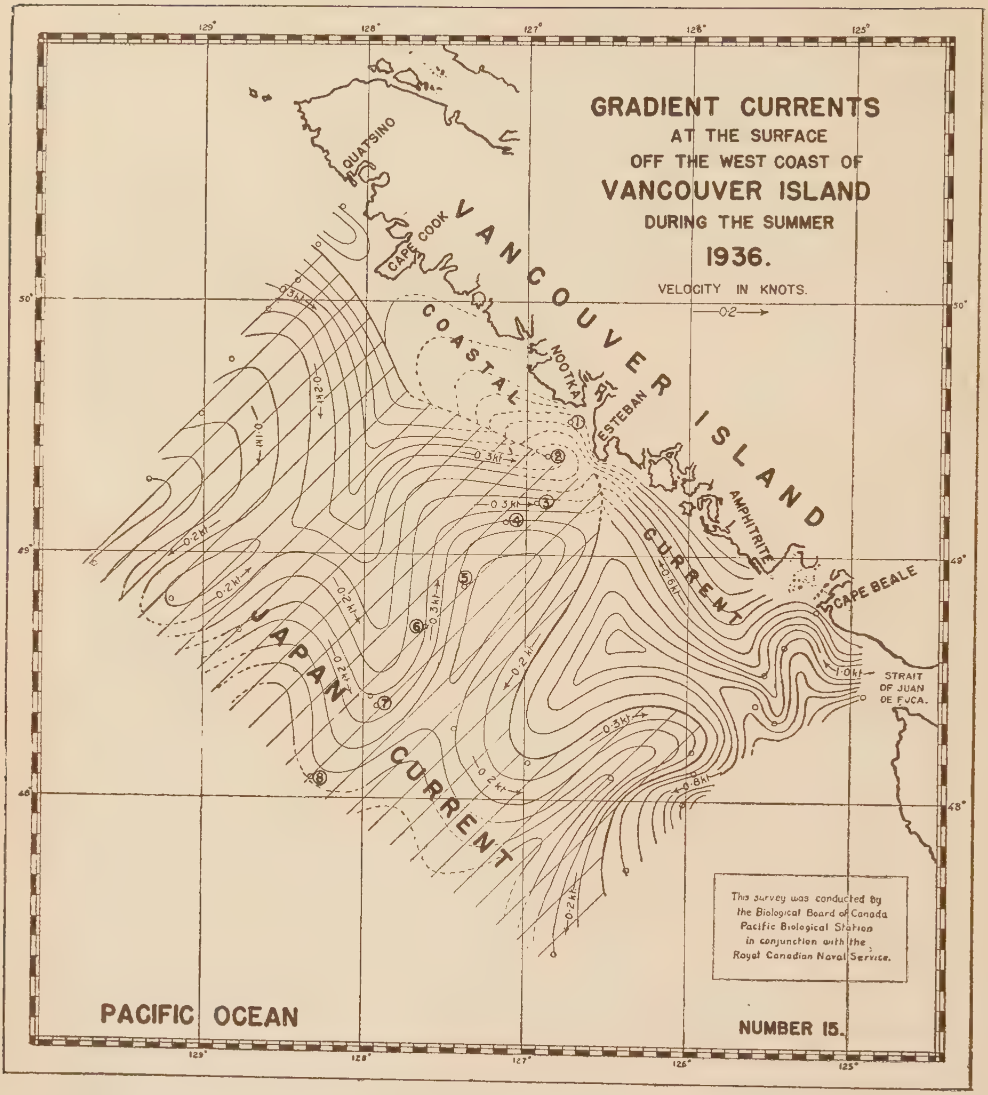

GRADIENT CURRENTS
AT THE SURFACE
OFF THE WEST COAST OF
VANCOUVER ISLAND
DURING THE SUMMER
1936.
VELOCITY IN KNOTS.
0·2
VANCOUVER ISLAND
QUATSINO
CAPE COOK
NOOTKA
ESTEBAN
AMPHITRITE
CAPE BEALE
STRAIT OF JUAN DE FUCA.
COASTAL CURRENT
JAPAN CURRENT
PACIFIC OCEAN
NUMBER 15.
This survey was conducted by the Biological Board of Canada Pacific Biological Station in conjunction with the Royal Canadian Naval Service.
0·3kt
0·2kt
0·1kt
0·6kt
0·8kt
1·0kt
① ② ③ ④ ⑤ ⑥ ⑦ ⑧
129° 128° 127° 126° 125°
50° 49° 48°

FIG. 9

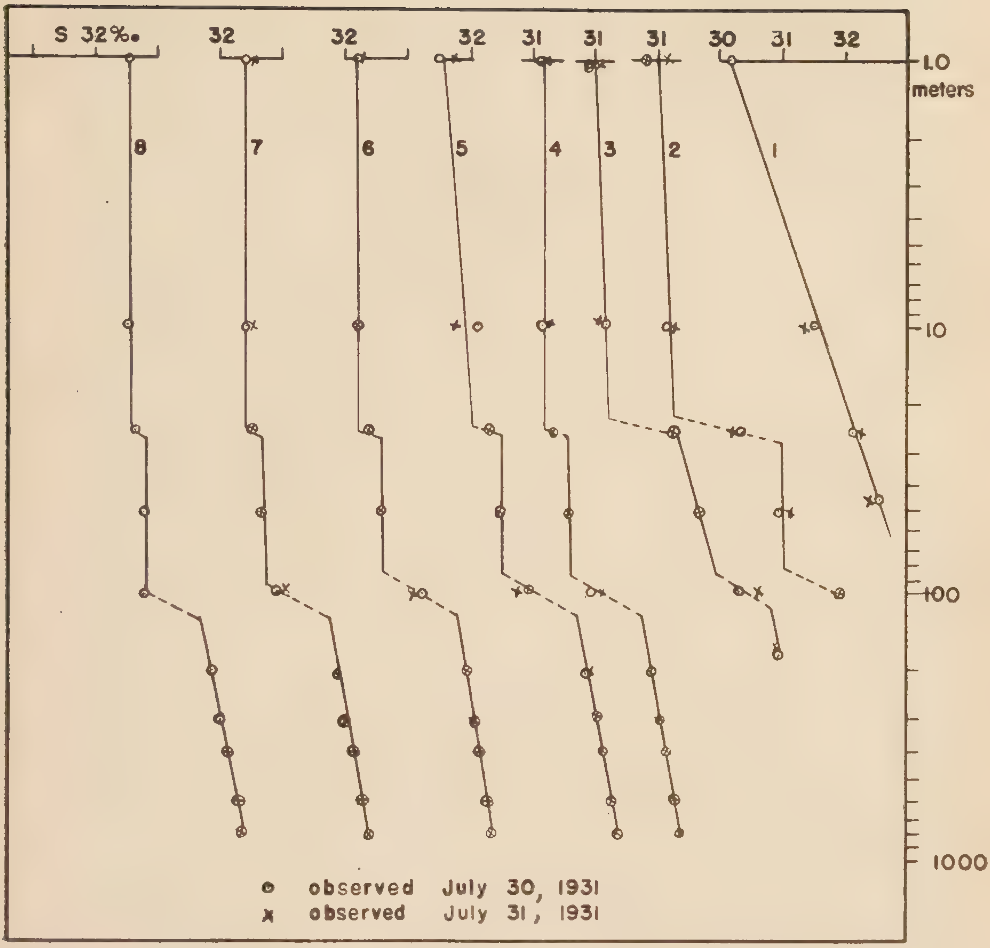


FIG. 10.—Gradients off the Pacific Coast of Canada (observed at positions marked in Fig. 9)

and is therefore insignificant. In the open sea the gradient flow is evidently preponderant, although it is reasoned that the former should be significant in the immediate vicinity of the coast, where seaward displacement is a necessary condition for removal of fresh water. Doubtless an intermediate state exists in partially enclosed seaways, such as illustrated in Fig. 7, where both gradients and displacement components are considerable.

It may be remarked in the gradient current chart (Fig. 9) that the " fresh-water influence " appears to veer to the right on entering the sea, and moves coastwise until it encounters a second outflow. Then it backs to the left and joins the great ocean stream. From the cross-sections it appears that the coastal current occupies the whole depth along the shore. As this water moves along the coast it encounters a second outflow and is evidently displaced seaward by the fresher outflow. In the new position the northward course is opposed by the prevailing winds from the north-west and the Japan current, which are evidently greater forces than those involved in the gradient flow. The component of seaward displacement causes the current to back to the left allowing the local fresh water to be dissipated in the ocean.

It is of interest to note that while the upper zone associated with the outflow of a particular river can be identified, the region of influence of that river can be defined. However, when the contributions from several outflows are degraded into a single structure, as illustrated in these last examples, the individuality of the parent river is lost.

The ultimate fate of this upper and intermediate zone have not been fully investigated, but it is remarked that in this and other local examples both of these zones become more saline to seaward, while the salinity of the lower zone remains constant. This implies that deep water is transferred upwards, but no fresh water is transferred downwards, across the boundary, and the mixing force is provided by the wind.

From these and similar examples it is reasoned that fresh water can only be transferred downwards in the sea by external accelerations, such as the wind, or tidal convergences, and in general these are limited to moderate depths. It follows that surface water remains on the surface, and when removed from the influence of coastal streams the salinity of the sea surface increases in the direction of flow because of progressive dilution with underlying sea-water and removal of fresh water by evaporation. The latter process completes the cycle, since all land drainage must be supplied by evaporation.

REFERENCES

(1) Tully, J. P. (1949): Oceanography of Alberni Inlet. In *Pub. of Bull. Fis. Res. Bd., Canada.*

(2) Cameron, W. M.: Oceanography of Chatham Sound. (MS. in preparation.)

(3) Tully, J. P.: Oceanography of Georgia Strait. (MS. in preparation.)

(4) ——— (1937): Oceanography of Nootka Sound. *J. Biol. Bd. Can., 3,* (1).

(5) Jacobson, A. W. (1948): An Instrument for Recording Continuously the Salinity, Temperature, and Depth of Sea Water. *Trans. Amer. Inst. Elec. Eng., 67.*

(6) Tully, J. P. (1942): Surface Non-tidal Currents in the Approaches to Juan de Fuca Strait. *Journ. Fish Res. Bd. Can., 5* (4).

(7) Marner, H. A. (1926): Coastal Currents Along the Pacific Coast of United States. *Pub. No. 121, U.S. Coast and Geodetic Survey.*

(8) Tully, J. P. (1937): Gradient Currents. *Prog. Rept. Fish. Res. Bd. Can.,* No. 33, Oct.

(9) Ford, W. L. (1947): Distribution of the Merrimack River Effluent in Ipswick Bay. *Tech. Rept. No. 3 on the Hydrography of the Western Atlantic, Woods Hole Ocean. Inst. Aug.*

(10) Rossby, C. G. (1937): On the Mutual Adjustment of Pressure and Velocity Distributions in Certain Simple Current Systems. *Journ. Mar. Res., 1,* 1.

(11) Spilhaus, A. F. (1937): Note on the Flow of Streams in a Rotating System. *Journ. Mar. Res., 1,* 1.

(12) Tully, J. P. (1935): Kurosio. *Prog. Rept. No. 25, Fish. Res. Bd. Can.*

(13) Tully, J. P.; Hollister, H. J.; Fjarlie, R. L. I.; and Anderson, W. (1949): A Hydraulic Model of Alberni Harbour. In publication, *Bull. Fish. Res. Bd. Can.*

(14) Tully, J. P. (1937): A Procedure for Increasing the Accuracy of Surface Current Charts Based on Hydrodynamic Observations. *Journ. Biol. Bd. Can., 3* (2).

SUMMARY OF DISCUSSION

Professor Yonge indicated that in his experience a vertical salinity gradient at points of entry of fresh water was not universal, and instanced the Bristol Channel, which seemed to illustrate a pure mixing of a horizontal wall. He admitted, however, that work done on the Tyne and in other localities does agree with Dr. Tully's results. How was the absence of a gradient accounted for in Bristol Channel? It was explained that in shallow water the opposition of strong tidal currents may create these effects.

Dr. Deacon stressed the importance of Tully's work; the biologists ask important and difficult questions which he thought it not yet possible to answer dogmatically. Tully's methods would very soon acquire the strongest importance in marine biology, and would be applied also to oceanic currents from one region to another.

SUMMARY OF DISCUSSION FOLLOWING ON JOINT SESSION OF OCEANOGRAPHY WITH BOTANY, ZOOLOGY, AND METEOROLOGY

Dr. Foerster opened by declaring that a challenge had been sent out by the papers of Drs. Spilhaus, Tully, and Deacon to the biological oceanographers to improve their methods in quantitative fish and plankton recording, and to make thereby full use of the physical data available for correlation. Mr. Powell commented that it might be difficult for fish observations to be sustained during a movement through the water at 20 knots.

Dr. Johnson stated that high-speed nets were being perfected at California Fish and Game and at Scripps Institutions. The stratification of occurrence of fish and plankton provided a difficulty, since there is a lack of comparable regularity in distribution as against the physical data. Dr. Miller pointed to the use of under-water listening-devices, and Dr. Johnson to the use for detection of outward sound.

Dr. Clements indicated some of the problems in which the biological oceanographers look to the physicochemical workers. We have not yet reached the desired goal of complete correlation, and, as Dr. Deacon had pointed out, we have still quite a long way to go before the physical oceanographer is able to supply all the information the biologist needs. Dr. Johnson hoped that the physical oceanographers would take to heart the dictum that the real justification for physical oceanography is in the assistance rendered to biology. Dr. Deacon confessed that it was as yet difficult to cite an example of direct benefit to fisheries from the work of the physical oceanographers. However, several speakers referred to the use of echo-sounding in fish detection off the Norwegian coasts. During his work with the "Discovery" expedition Dr. Deacon had, however, come up against definite clearly stated problems in which the aid of the physical oceanographer was sought. He laid stress on the need for careful formulation of problems. He instanced the field of whale research, where a definite fluctuation in abundance of whales from year to year was correlated with variations in the supply of euphausids, which in turn was correlated with physical conditions. He begged the biologists to be very patient for a while yet with the physical school.

Speaking for the meteorologists, Dr. Spilhaus deplored the fact that none of the American weather ships make oceanographic observations. This was shortsighted even from the meteorologists' point of view. For instance, oceanic atmospheric energy exchange data would be very relevant in meteorology. Dr. Tully spoke of the project to record hydrographic sections off the west coast of Canada. It was obvious that more joint meetings were required between the two sciences.

SOME RECENT TEMPERATURE SECTIONS ACROSS THE ANTARCTIC CONVERGENCE

By D. W. Pritchard and E. C. LaFond, U.S. Navy Electronics Laboratory, San Diego 52, California

Introduction

The temperature data discussed in this paper represent a portion of the oceanographic information obtained during the U.S. Navy Antarctic Development Project of 1947 (operation HIGHJUMP). In order to secure these oceanographic data Dr. Robert S. Dietz and Mr. Herbert J. Mann, civilian representatives of the U.S. Navy Electronics Laboratory, accompanied two of the ships of the Western Task Group—The U.S.S. " Henderson " and the U.S.S. " Cacopan "—on operation HIGHJUMP. A treatment of all of the oceanographic and geological data obtained by the Western Task Group on this operation is presented in *USNEL Report No. 55, Some Oceanographic Observations on Operation HIGHJUMP, July, 1948.* This paper deals with five bathythermograph sections made by individual ships while crossing the Antarctic Convergence.

General

Proceeding southward from the region of warm surface water in low latitudes one encounters first gradually decreasing temperatures. However, in a region between 55° S. and 65° S. the temperature decreases markedly within a short distance. Beyond this region of strong horizontal temperature gradients the surface temperatures remain rather constant and near the freezing-point. This boundary is a region where part of the cold Antarctic surface water, brought northward by the transverse circulation created by the westerly wind system, sinks below the warmer water transported southward by the thermohaline circulation which dominates in the subantartic region. This area of sinking is called the " Antartic Convergence."

As reported by Dr. Dietz, the convergence was quite apparent as an abrupt water-mass boundary in the south central Pacific, north of the Ross Sea. Soon after crossing it, observers on the " Henderson " encountered their first group of icebergs. As the convergence was crossed the water changed in colour from blue to grey, new types of birds appeared, and the sky cleared. These changes closely followed the drop in temperature, which was more than 2·5° C. in about 20 miles.

Location of the Convergence

To aid in locating the Antarctic Convergence, as well as to show the complexities of the antarctic thermal structure, horizontal temperature plots and vertical cross-sections of temperature versus depth have been constructed for five locations as shown in Figure 1. The horizontal plots are numbered A, B, C–1, C–2, and C–3 for reference.

Both the plots and cross-sections are based on a series of bathythermograph observations taken by individual ships on nearly straight runs across the convergence. Three of the sections—C–1, C–2, and C–3—were taken in the same locality and serve to indicate the seasonal trends in the location of the convergence. These features are discussed more fully below.

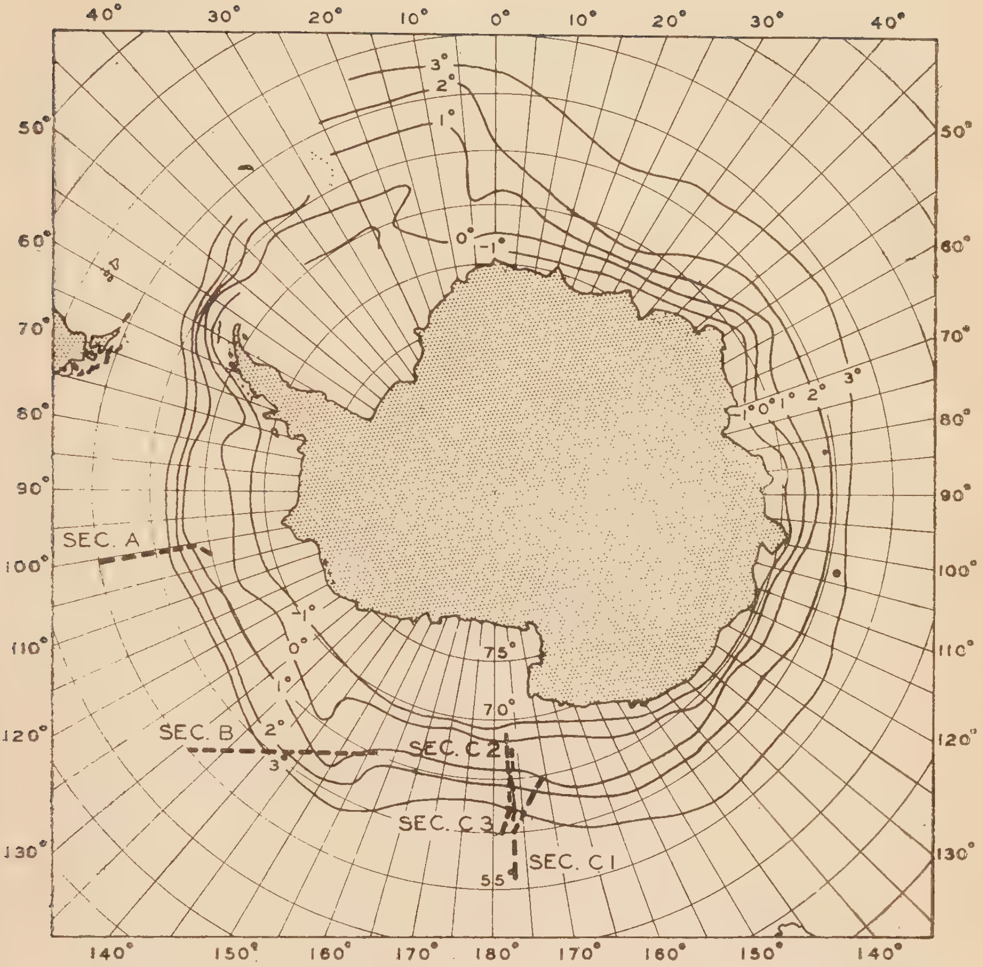

40°
30°
20°
10°
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
130°
140°
150°
160°
170°
180°
170°
160°
150°
140°
3°
2°
1°
0°
-1°
-1°
0°
1°
2°
3°
-1°
0°
1°
2°
3
SEC. A
SEC. B
SEC. C 2
SEC. C 3
SEC. C 1
75°
70°
55°

FIG. 1.—Location of five crossings of the Antarctic Convergence (sections A, B, C–1, C–2, and C–3)

HORIZONTAL SURFACE-TEMPERATURE SECTIONS

Ideally, if the surface temperatures were plotted against latitude, with temperature as the vertical co-ordinate and latitude as the horizontal co-ordinate, the Antartic Convergence should appear on such a plot as a sharp break in the slope of the surface-temperature curve. A schematic presentation of such a graph under ideal conditions is shown in Fig. 2.

When actual observed values of surface temperatures are plotted in the above fashion erratic variations of the surface temperature complicate the picture considerably (see Fig. 3). The more observations available, the more complex the surface-temperature fluctuations appear. They are related to variations in meteorological conditions, currents, and melting ice, as well as to the convergence circulation. However, in each section the characteristic break in temperature is easily discernible.

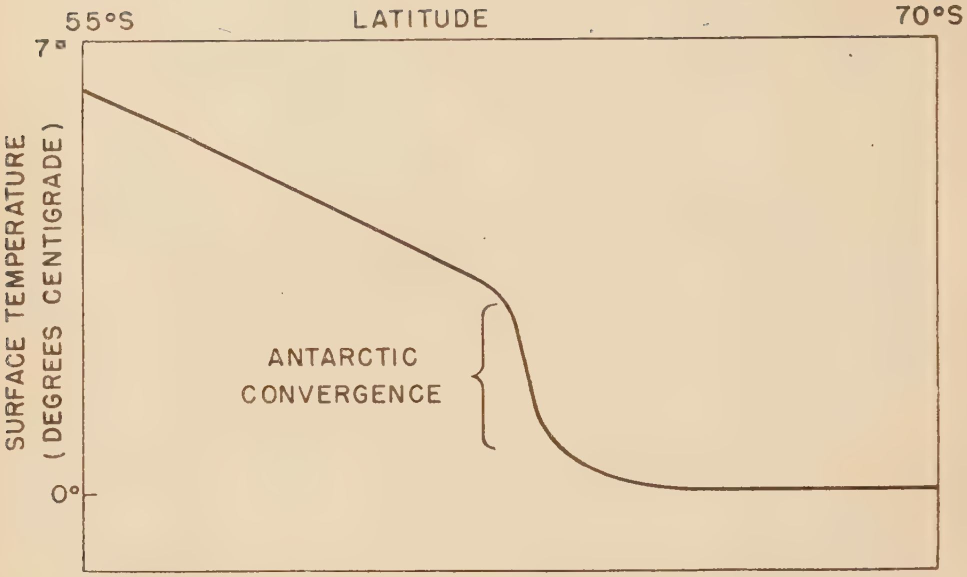


FIG. 2.—Schematic representation of a surface—temperature section across the Antarctic convergence

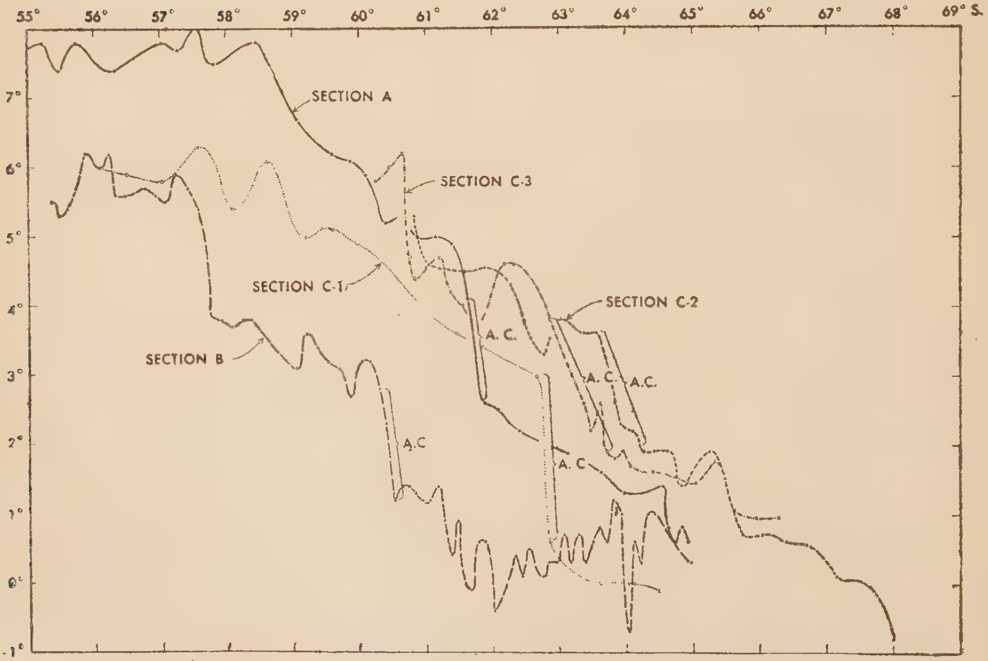


FIG. 3.—Observed surface-temperature sections across the Antarctic Convergence

Section A was taken during late December along a north–south line which closely followed the 100° W. meridian. The sharp break in slope of the surface-temperature plot is apparent at about 61° 47′ S., with a mean temperature of 3·2° C. on the steepest part of the slope (see Table 1). This is a higher temperature than was observed at the convergence on any of the other sections. The surface temperature decreases about 2·2° C. in a distance of 20 miles.

In section B, which lies 40° to the west of section A, the large temperature gradient indicative of the convergence was found much farther north, at 60° 24′ S. The observations are more closely spaced in this section and consequently give a more complex temperature structure. The temperature gradient at the convergence on this section is about 2·0° C. in 15 miles.

Sections C–1, C–2, and C–3, which are all in one locality, give indications of seasonal changes in the surface temperatures at the convergence. In section C–1 the convergence was found early in the season at 62° 46′ S., with a mean temperature of about 1·8° C. This is the most striking break in temperature found. The decrease is 2·5° C. in a distance of 10 miles. Section C–2, taken fifty-four days later, shows the convergence at 63° 50′ S., with a mean temperature of 2·7° C. This indicates that the convergence had moved south about 64 miles and the temperature at the convergence increased by 0·9° C. The temperature gradient decreased to 1·8° C. in 30 miles. The third section in the same longitude shows that the convergence moved back to the north to about 63° 20′ S., with a mean temperature of 2·8° C. This northerly displacement amounts to 30 miles in a period of fourteen days. The surface temperature gradient here is 2·8° C. in approximately 80 miles. A summary of the surface temperature characteristics at the convergence is contained in Table 1.

TABLE 1—LOCATION OF SURFACE TEMPERATURE SECTIONS ACROSS THE ANTARCTIC CONVERGENCE

Section.	Date.	Latitude.	Longitude.	Antarctic Convergence. Latitude	Antarctic Convergence. Temperature. (Degrees C.).
A	23–25 Dec.	55°–65° S.	100° 30′–102° 30′ W.	61° 47′ S.	3·2
B	25–28 Dec.	55°–65°	131° –156°	60° 24′	2·0
C–1	21/23 Dec.	56°–65°	176°	62° 46′	1·8
C–2	13–16 Feb.	60°–68°	176°	63° 50′	2·7
C–3	27 Feb.–1 Mar.	60°–67°	176°	63° 20′	2·8

VERTICAL TEMPERATURE SECTION

The convergence should be marked at subsurface depths by a continuation of the sharp gradients found at the surface. Another important indication of the northern limit of the antarctic region, and hence of the location of the Antarctic Convergence, is the position of the northern boundary of the subsurface temperature minimum which develops in summer. This temperature minimum marks the remainder of the winter-cooled layer. During the period of active cooling a surface layer of nearly homogeneous water develops throughout the Antarctic region, with a temperature near freezing. Below this isothermal layer, which extends to about 300 ft. below the surface, there is a transition region in which the temperature increases with depth. This transition layer lies between the surface layer and the antarctic circumpolar water. This latter is a large, well-defined water mass, characterized by a temperature maximum of slightly more than 2° C., at a depth of between 1,500 and 2,000 ft. In summer, during the period of increased radiation, the surface layers are warmed. The resulting temperature increase seldom extends below 150 ft.; consequently, at a depth of from 200 to 500 ft. there remains a cold layer of winter-cooled water. North of the Antarctic Convergence the temperature continuously decreases with depth, and the typical minimum at 200 to 500 ft. is not developed. This subsurface temperature structure characteristic of the Antarctic Convergence is demonstrated by vertical cross-section plots of the five crossings (see Figs. 4 and 5). On these cross-sections all areas below zero degrees Centigrade have been shaded in order to indicate the location of the subsurface minimum.

In the vertical section shown in Fig. 4 (*a*) the temperature gradient between 2 and 3·5° C. continues to mark the convergence as it slopes downward to the north below the warmer subantarctic surface water. Taking the 3° C. isotherm as indicative of the location of the boundary between the two water masses at the convergence zone, it is seen that this boundary has a slope downwards towards the north of 3×10^{-3} in the upper 400 ft.—that is, the cold Antarctic intermediate water sinks below the warmer subantarctic surface water at the rate of 18 ft. for each mile to the north. South of the Antarctic Convergence the typical area of subsurface minimum temperature does not appear well developed.

The vertical temperature cross-section shown in Fig. 4 (*b*) is particularly interesting since bathythermographs were taken at very short intervals in the southward progress of the U.S.S. "Northwind." The detail shown here clearly indicates that the usual cross-section, drawn from stations separated by much larger intervals, presents a very smoothed picture of the vertical thermal structure. The apparent thermal structure is very complex, appearing more and more complicated with greater observational detail. Internal waves may contribute considerably to the complicated thermal structure shown here.

The boundary zone in this vertical temperature section (Fig. 4 (*b*)) is fairly well marked at subsurface depths between the 1° C. and the 3° C. isotherms. This zone has an average slope of about 4×10^{-4} in the upper 300 ft. The region of subsurface temperature minimum, shown by the shaded area of temperatures less than zero degrees Centigrade, is well marked in this section. The northern limit of this area occurs just north of the convergence, and serves as a further indication of the location of the boundary zone.

The three vertical sections of Fig. 5, sections C–1, C–2, and C–3, all show a fairly well-defined boundary zone at subsurface depths, as indicated by the temperature gradients. These sections were all taken approximately along the same north-south line and serve not only to demonstrate the fluctuations with time in the location of the convergence, but also to show the seasonal development of the subsurface temperature minimum. On vertical section C–1 the structure a short distance south

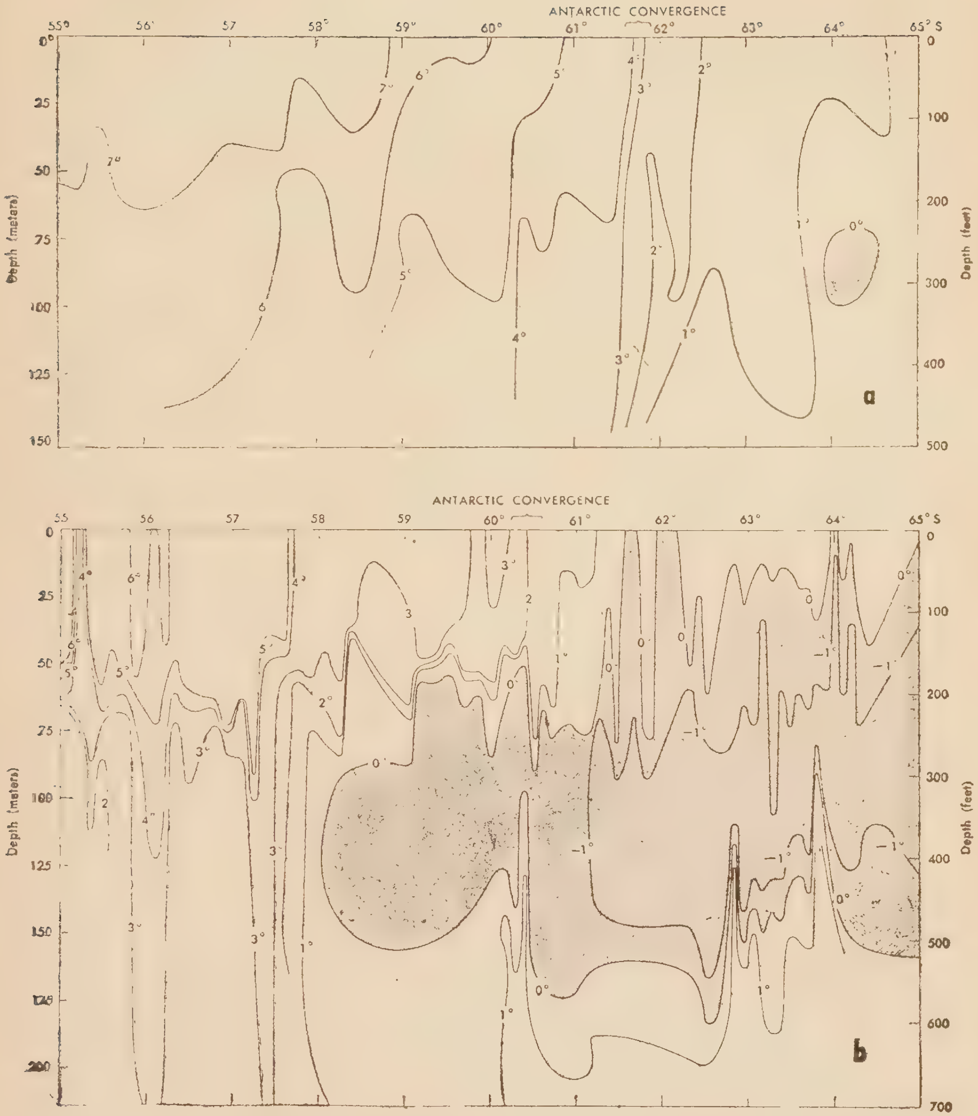


FIG. 4.—Vertical temperature sections across the Antarctic Convergence

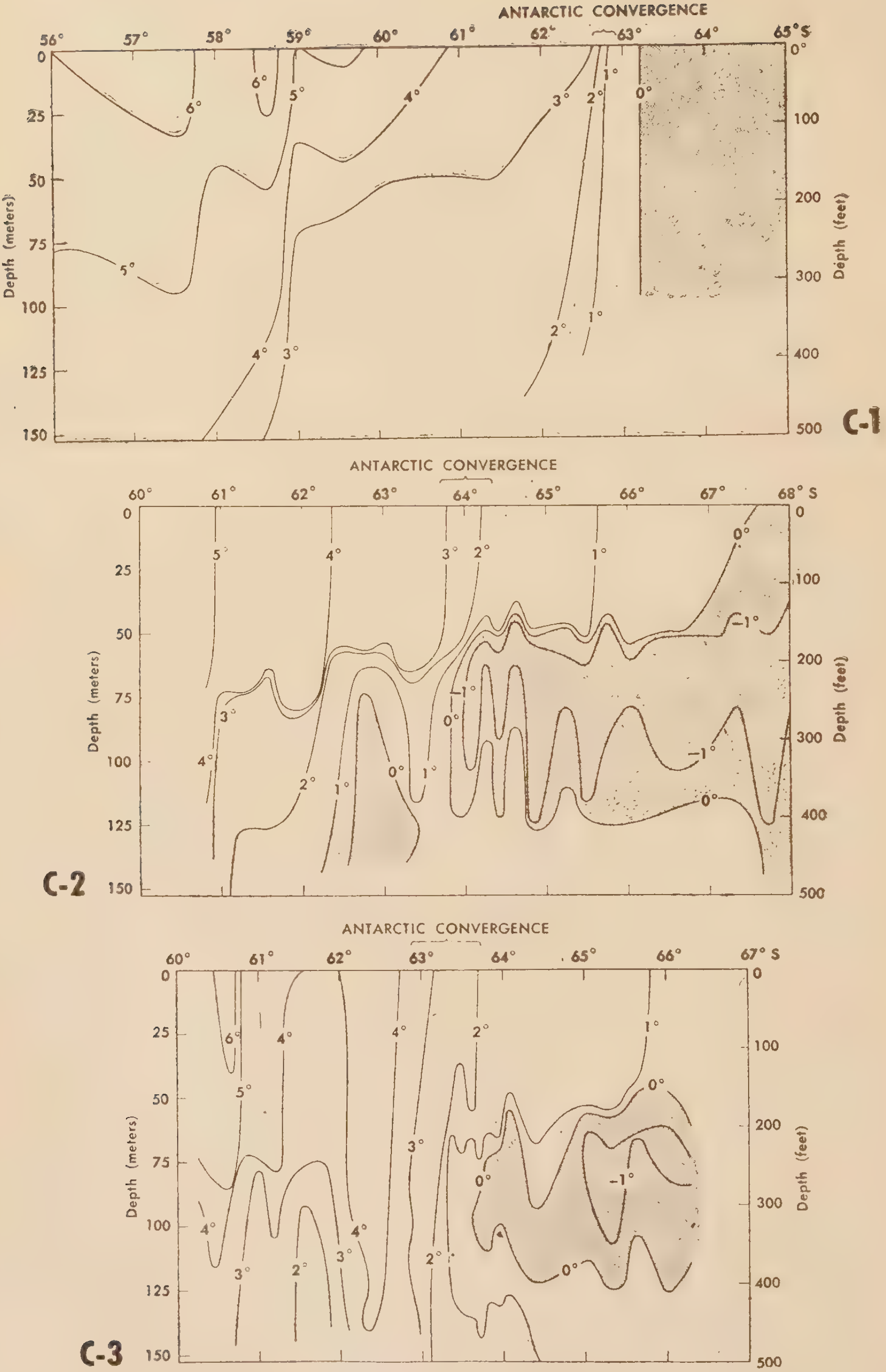


FIG. 5.—Vertical temperature sections across the Antarctic Convergence

of the convergence shows a nearly isothermal surface layer with temperatures below zero degrees Centigrade. The increase in temperature in the transition layer at greater depths does not appear here because of the shallowness of the section. Section C–2, taken fifty-four days later, indicates that surface heating has produced an area with a well-marked subsurface minimum. The data in this section extend deep enough to penetrate the region of positive gradient. Section C–3 shows this subsurface minimum and its northern boundary, serving as an indication of the location of the boundary zone.

The southward displacement of the convergence in the fifty-four-day period between sections C–1 and C–2 may be related to an increase in the thermohaline circulation in the subantartic region, coupled with a decrease in the intensity of the transverse circulation related to the prevailing westerlies in the Antartic region. This displacement appears to be a seasonal phenomenon, with the convergence occurring farther south in summer than in the colder months. In winter the cold antarctic water extends farther north along the surface before sinking to form the antarctic intermediate water at the convergence. The northward displacement of the convergence between sections C–2 and C–3 may indicate that the southward seasonal trend has been reversed by late February, when section C–3 was obtained.

ON THE CORRELATED FLUCTUATION OF THE KUROSIO CURRENT AND THE COLD WATER MASS

By Mititaka Uda, Nagasaki Marine Observatory, 1949. *Oceanographical Mag.*, Vol. 1, No. 1. [*Read by title only.*]

ON THE VERTICAL EXTINCTION COEFFICIENT OF SEA-WATER IN THE PACIFIC COAST OF JAPAN

By Yositada Takenouti, Hakodate Marine Observatory

1. Introduction

The vertical extinction coefficient of sea-water has been measured by many authors at various localities of the world since Professors H. H. Poole and W. R. G. Atkins had made their famous observations in the English Channel by means of a photovoltaic cell. As for the Pacific Ocean, Professor C. L. Utterback and his collaborators have made many measurements in the north-eastern part of the ocean. In the western part of the Pacific Ocean, however, a submarine illumination had been scarcely measured. The author has made a series of observations for under-water illuminations in waters near Japan and the Japanese lakes, and he gave a standard value of vertical extinction coefficient of sea-water as a function of wave-length for every class of the colour of sea.

2. Instrument and Method of Measurement

A photovoltaic cell made by the Tokyo Electric Co., named " Mazda photo-cell," has been employed for the measurement of under-water illuminations. The aperture of the cell is 40 mm. in diameter. The normal spectral sensitivity of Mazda photocell is illustrated in Fig. 1, which is reproduced from the monograph written by Dr. H. Suzuki, an expert of the Tokyo Electric Co. The spectral sensitivity of the cell resembles that of the human eye, but is somewhat more sensitive for the ultraviolet and infrared regions. The sensitivity of the cell for white light is about 0·5 microamperes per lux; the sensitivity had, however, been measured for each cell before the measurement of under-water illuminations comparing with a standard photo-cell provided by the same company.

The photo-cell is put in a bronze casing with a window covered by a thick glass, the thickness of the glass is 5 mm. and the aperture of window is 60 mm. The photo-cell is connected to instruments on board a boat by means of a two-core cable covered with rubber sheath. Above the thick glass an opal glass is laid, the upper surface of the opal glass is adjusted to be at the same plane to the surface of frame clamping the window glass, so as to introduce the whole light rays coming from the upper hemi-sphere under the sea.

Between the opal glass and the window glass a light-filter is inserted in order to limit the under-water illumination in a narrow band of spectrum. The light-filters used in the present investigations are manufactured by the Tokyo Electric Co. The spectral response of the photo-cell with the filters are also illustrated in Fig. 1. The optical centre of spectral response for each filter is shown by a short arrow in the figure. The wave-lengths of them are 665, 645, 615, 570, 535, 495 and 405 μ for the filters V–R1, V–R2, V–R3, V–O1, V–G1, V–B1, and V–V1 respectively.

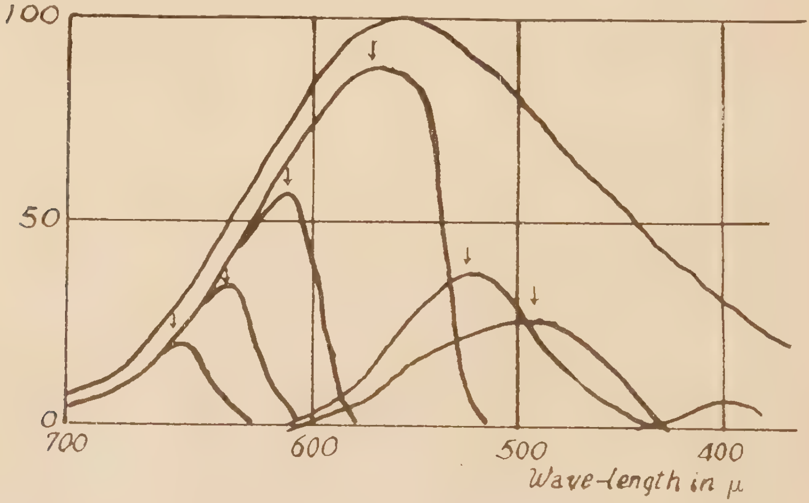


FIG. 1.—Spectral sensitivity of Mazda photo-cell and the spectral response of the cell with filters

A photo-current from the under-water photo-cell is measured by means of an ammeter installed on board a boat. Between the cell and the ammeter a key- and resistance-box is inserted, which contains shunt resistances for the ammeter to alter a range of measurement, as well as a switch to connect the ammeter to the under-water photo-cell and a cell laid horizontally on a deck of boat alternatively. The internal resistance of ammeter is 50 ohms, and the full scale is 150 micro-amperes. Although a Mazda photo-cell generally has a linear relation between a photo-current and an illumination for an outer resistance smaller than 100 ohms, some of the cells used in the present investigations had shown a discrepancy from the linear relation. For such cells the following formula has been used to calculate the intensity of illumination from the reading of micro-ammeter—

$$\log L = (a + bI) \log I,$$

where L is an intensity of illumination, I is a reading of micro-ammeter, and a and b are constants obtained by an experiment for each cell. Generally b is very small and we are able to regard $(a + bI)$ as a constant, then we can calculate the vertical extinction coefficient of sea-water by the following formula—

$$k = 2{\cdot}303\ (a + bI)\ (\log I_1 - \log I_2)\ /\ (D_1 - D_2)$$

where D_1 and D_2 are depths at which under-water illuminations are measured and the intensities of illuminations at the depths are I_1 and I_2 respectively, and k is a vertical extinction coefficient of sea-water. For most of photo-cell a is unity and b vanishes, then the above formula becomes—

$$k = 2{\cdot}303\ (\log I_1 - \log I_2)\ /\ (D_1 - D_2)$$

3. RESULTS OF MEASUREMENT

The present investigations have been carried out from 1940 to 1944. Localities were restricted to the coastal waters of north-eastern part of Japan, which are illustrated in Fig. 2.

At most stations under-water illuminations were measured for three parts of spectrum, red, green, and violet light. The relations between the vertical extinction coefficients for these three bands of spectrum are illustrated in Fig. 3. In this figure the results obtained by other authors for the similar bands of spectrum at various localities are also reproduced simultaneously. It is noticeable from the figure that the relations between the vertical extinction coefficients for the different bands of spectrum are rather scattered, accompanied with the change of season as well as of localities. As an average relation between them we get following formulæ, which are also illustrated in the figure by straight lines—

$$k_v = 4{\cdot}8\ k_g 1{\cdot}5,$$

and

$$k_r = 0{\cdot}89 k_g 0{\cdot}5, \text{ when } k_g \text{ is smaller than } 0{\cdot}2,$$
$$k_r = 1{\cdot}25 k_g 0{\cdot}8, \text{ when } k_g \text{ is greater than } 0{\cdot}2,$$

where k_v, k_g, and k_r are the vertical extinction coefficients for violet green and red light respectively. The relations between the violet and green light are expressible by a single function. Between red and green light, however, it must be expressed by two different functions. Following conclusions are supposed from this fact: seston in sea-water equally increase the vertical extinction coefficients for green and violet light, but for red light they are less effective than for green and violet light so long as their total amounts are not enormous. In the very turbid sea-water, when the vertical extinction coefficient for green light exceeds 0·2—about ten times greater than for pure water—the effects of seston upon the vertical extinction coefficient for red light increase as well as for green and violet light, then a new relation between them appears.

The results of measurements are classified according to the colour of sea in Forell's scale. In the table, a result of measurement at the stations where more than five filters are used simultaneously are

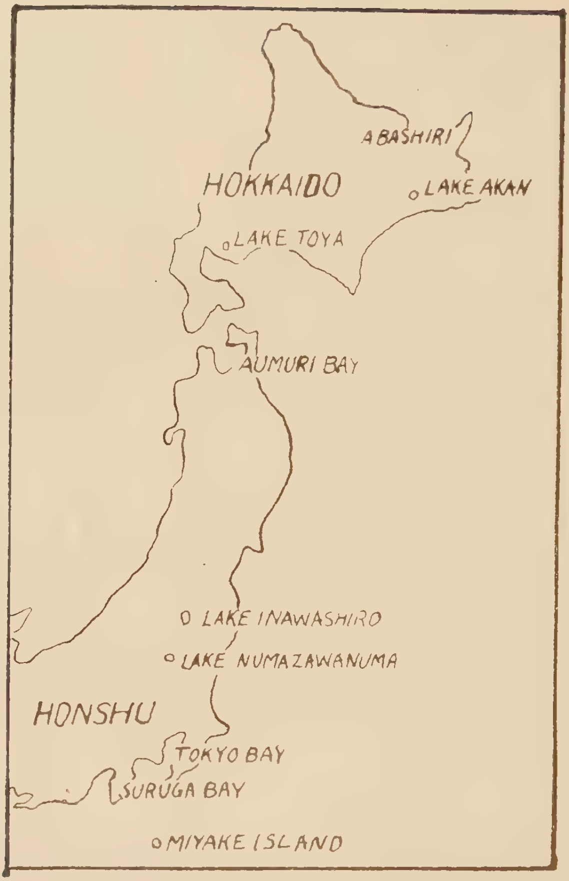

ABASHIRI
HOKKAIDO
LAKE AKAN
LAKE TOYA
AUMURI BAY
LAKE INAWASHIRO
LAKE NUMAZAWANUMA
HONSHU
TOKYO BAY
SURUGA BAY
MIYAKE ISLAND

FIG. 2.—Showing the localities of observations

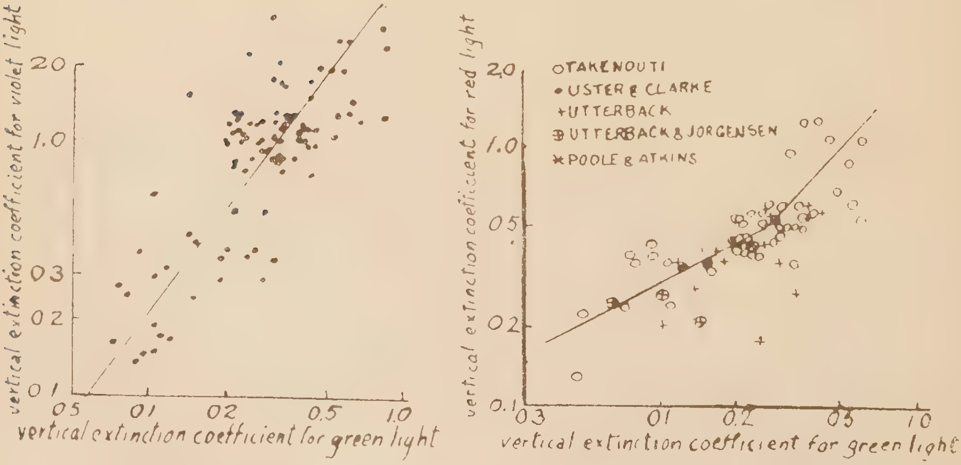


FIG. 3.—Showing the relations between the vertical extinction coefficients for different colour of light

shown, while in order to calculate the average values of vertical extinction coefficients for each class of colour of the sea, whole results of measurements are used irrespective of the numbers of filters employed.

TABLE 1—THE VERTICAL EXTINCTION COEFFICIENT FOR EVERY CLASS OF COLOUR OF SEA IN FORELL'S SCALE

Localities.		Trans-parencies.	Vertical Extinction Coefficient.							Date.
			V–R1, 665.	V–R2, 645.	V–R3, 615.	V–O1, 570.	V–G1, 525.	V–B1, 495.	V–V1, 405.	
5	Off Miyake Island	15·0	..	..	0·442	0·119	0·095	0·110	0·140	Oct., 1943
	L. Numazawanuma	11·5	0·449	0·355	0·242	0·091	0·076	0·128	0·160	Aug., 1943
	Suruga Bay ..	12·0	0·915	0·536	0·378	0·100	0·098	0·115	0·145	Dec., 1943
	Mean ..	..	0·682	0·446	0·310	0·096	0·087	0·122	0·154	..
9	Lake Toya ..	15·0	0·870	..	0·349	0·144	0·083	..	0·250	Aug., 1942
	Amori Bay ..	11·5	..	..	0·346	0·131	0·123	0·118	0·188	Oct., 1940
	Lake Inawashiro ..	8·5	0·740	0·466	0·340	0·132	0·119	0·134	0·171	Aug., 1943
	Mean ..	..	0·809	0·466	0·388	0·136	0·108	0·126	0·203	..
14	Amori Bay ..	9·0	0·850	..	0·450	0·138	0·119	0·373	0·525	Oct., 1941
20	Lake Akan ..	11·5	0·581	..	0·359	0·179	0·165	..	0·411	Aug., 1942
	Off Abashiri ..	8·0	0·829	..	0·148	0·141	0·081	..	1·6	Aug., 1942
	Tokyo Bay* ..	4·0	1·324	..	0·511	0·327	0·336	..	0·926	April, 1943
	Mean ..	..	1·002	..	0·448	0·254	0·270	..	0·994	..
27	Akkeshi Bay ..	6·5	0·766	..	0·376	0·505	0·111	..	0·301	Aug., 1942
	Tokyo Bay ..	4·0	0·944	..	0·615	0·322	0·401	..	1·07	April, 1943
	Tokyo Bay ..	3·6	0·982	0·474	0·304	0·141	0·223	0·265	0·819	July, 1943
	Tokyo Bay ..	3·0	0·857	..	0·622	0·322	0·336	..	0·921	April, 1943
	Mean ..	..	1·012	..	0·525	0·310	0·326	0·459	0·903	..
35	Tokyo Bay ..	3·1	1·345	..	0·341	0·304	0·345	..	0·700	April, 1943
	Tokyo Bay ..	2·5	1·032	..	0·587	0·325	0·405	..	1·105	April, 1943
	Tokyo Bay ..	1·4	1·068	1·087	0·676	0·334	0·416	0·671	1·150	Feb., 1944
	Mean ..	..	1·118	0·555	0·436	0·315	0·348	..	1·193	..
44	Tokyo Bay† ..	2·5	1·204	..	0·643	0·369	0·399	..	0·955	April, 1943
	Mean ..	..	1·247	0·936	0·670	0·336	0·398	0·577	1·202	..
54	Tokyo Bay ..	1·7	1·240	0·733	0·510	0·272	0·359	0·483	1·202	May, 1943
	Mean ..	..	..	..	0·683	..	0·401	..	1·190	..
65	Tokyo Bay ..	2·0	2·275	0·987	1·055	0·471	0·540	0·703	1·643	June, 1943

*Mean of 4 st. with equal transparency. †Mean of 5 st. with equal transparency.

In the table the first column shows the colour of sea by Forell's scale. The localities of observations are shown in the second column, the third column shows the transparency of sea-water, which has been measured by a white disk of about 30 cm. in diameter. The vertical extinction coefficients are shown in the table from the fourth to eleventh columns, the kinds of filters and the optical centers of response for each of them are written at the heads of columns. The last column shows the date of observations.

Among the average values of vertical extinction coefficients in the table some irregularities which cannot be negligible remain still. In order to eliminate the irregularities the values of extinction coefficients are plotted on a sheet taking the wave-length of light as an ordinate and the value of vertical extinction coefficient as an abscissa. Considering the relations between the vertical extinction coefficients for red (V-R3), green (V-G1), and violet (V-V1), the points representing them are connected smoothly for all classes of Forell's scale. Thus we get

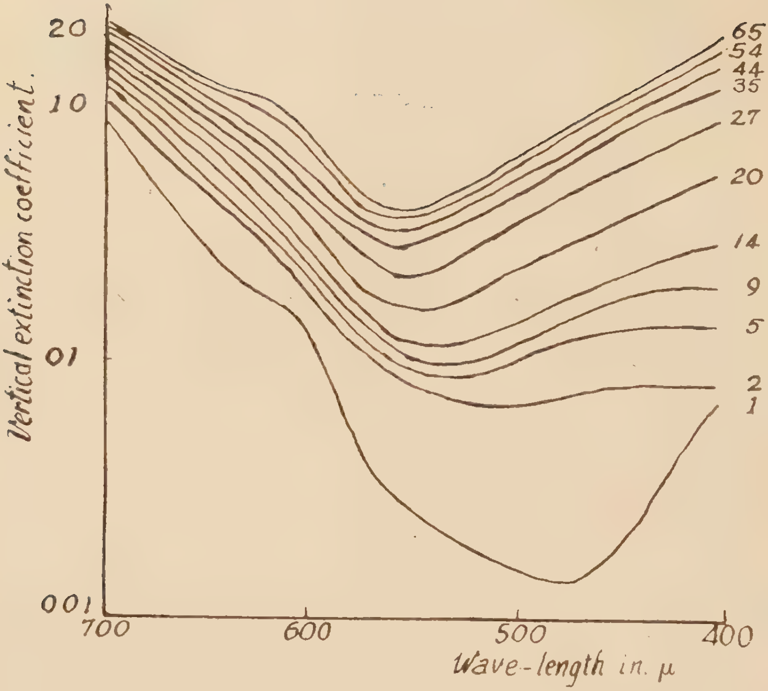


FIG. 4.—Showing the average values of vertical extinction coefficients of sea-water

Fig. 4, which gives the average vertical extinction coefficients of sea-water for all classes of Forell's scale. In this figure the results of Professors C. L. Utterback and W. Jorgensen for deep sea-waters and the absorption coefficient for distilled water by W. R. Sawyer are also reproduced (line (2) and (1) respectively).

Looking through the figure we noticed that the most transparent wave-length moves towards the side of long wave as the colour of sea becomes yellowish. The change of wave-length is, however, more remarkable for bluish transparent sea-water. The minimum vertical extinction coefficients and the wave-lengths for them are shown in table 2.

TABLE 2—MINIMUM VERTICAL EXTINCTION COEFFICIENTS

The Colour of Sea.	Minimum of Vertical Extinction Coefficient.	Wave-length for Minimum Vertical Extinction Coefficient.	Transparency.	
			Mean of Stations of Observation.	Average of Near Japan.
5	0·088	530μ	15·1m	16·1m
9	0·098	539	10·9	10·6
14	0·112	544	8·0	7·0
20	0·149	550	4·9	4·0
27	0·228	556	4·0	3·6
35	0·297	558	3·3	2·8
44	0·332	559	2·9	2·1
54	0·389	560	2·3	1·8
65	0·416	561	2·0	1·5

In the table mean values of transparencies at the stations of observation as well as the average value for each class of Forell's scale in the waters near Japan, which are calculated by Dr. M. Uda, are reproduced. The former is rather large for yellowish colour of sea. This is probably due to the fact that in some stations the turbid riverine water covered over sea-water and it makes the colour of sea yellowish. The transparency, however, remains almost unchanged owing to the film of riverine water being very thin. This phenomena is frequently observed in a bay into where a great river empties.

The products of the transparencies and the vertical extinction coefficients are almost constant for every class of colour of sea. The value of product is, however, about a half that obtained by Professors H. H. Poole and W. R. G. Atkins for the waters of English Channel. This is natural, because in the case of our experiments the minimum values of vertical extinction coefficients are used to calculate the product.

LITERATURE

(1) Poole, H. H., and Atkins, W. R. G.: Photo-electric Measurement of Submarine Illumination Through the Year. *Journ. Mar. Biol. Assoc.*, XVI, p. 297, 1029.

(2) Uda, M.: The Colour of Sea and Transparency in Waters Near Japan. *Umi to Sora* (in Japanese), X (8), p. 173, 1930.

(3) Sawyer, W.: The Spectral Absorption of Light by Pure Water and Bay of Fundy Water. *Contr. Canad. Biol. Fish.*, N.S. (8), 1941.

(4) Poole, H. H. and Atkins, W. R. G.: The Use of a Selenium Rectifier Photocell for Submarine Photometry. *Journ. Mar. Biol. Assoc.*, XIX, p. 727, 1932.

(5) Utterback, C. L. and Jorgensen, W.: Absorption of Daylight in the North Pacific Ocean. *Journ. du Conseil*, IX, p. 157, 1934.

(6) Suzuki, H.: Photo-electric Cell and Photo-voltaic Cell. (In Japanese.) Tokyo, 1938, p. 342.

RECENT ADVANCES IN CHEMICAL OCEANOGRAPHY IN JAPAN

By M. Ishibashi, Science Faculty, Kyoto University

List of Titles in the Symposium, with References

1. On Lead Content in Sea-water and its Geochemical Meaning: The Age of the Ocean (1), by M. Ishibashi, M. Tanaka, and H. Hayakawa. 1943, *Journ. Oceanogr. Soc. Japan*, 2, 10.
2. On the Regularity of Quantities of Elements Dissolved in Sea-water: The Age of the Ocean (2), by M. Ishibashi and Y. Harada. 1943, *Journ. Oceanogr. Soc. Japan*, 2, 84.
3. On Lithium Content in Sea Water and Bittern, by M. Ishibashi and K. Kurata. 1936, *Journ. Chem. Soc. Japan*, 60, 1109.
4. On Rubidium Content in Sea Water and Bittern, by M. Ishibashi and Y. Harada. 1942, *Journ. Chem. Soc. Japan*, 63, 211.
5. On Caesium Content in Sea Water and Bittern, by M. Ishibashi and Y. Harada. 1943, *Journ. Chem. Soc. Japan*, 64, 1049 and 1944, *Journ. Oceanogr. Soc. Japan*, 3, 185.
6. On Thorium Content in Sea Water, by M. Ishibashi and S. Higashi. 1948, Reported at 69th Annual Meeting of Chemical Society of Japan.
7. On Vanadium in Sea Animals, by K. Kimura and R. Fukai. 1948, *Journ. Chem. Soc. Japan*, 69, 75.

8. Micro-determination of Uranium by the Fluorescence Method, by M. Nakanishi. 1943, *Journ Chem. Soc. Japan*, 68, 42.

9. Copper, Lead, and Zinc Content in Sea Water, by K. Kuroda. 1940, *Bull. Chem. Soc. Japan*, 15, 441.

10. Chemical Composition of Deep Sea Muds in the Pacific Ocean : Red Clays and Radiolarian Oozes, by M. Ishibashi and Y. Harada. 1938, *Journ. Chem. Soc. Japan*, 58, 569.

11. A New Improved Method of Separation of Gold from Sea Water, by M. Ishibashi and Y. Harada. 1939, *Journ. Chem. Soc. Japan*, 60, 1265.

12. On Chemical Compositions of Boiler Scales Produced From Sea Water, by M. Ishibashi, M. Shinagawa, and T. Shigematsu. 1941, *Journ. Chem. Soc. Japan*, 62, 44, and *ibid.*, 1942, 63, 781.

13. On Inorganic Constituents of Sea Weeds, by M. Ishibashi and R. Sahara. 1940, *Journ. Chem. Soc. Japan*, 61, 277.

14. On Separation and Quantitative Analysis of Halogens in Sea Weeds, by M. Ishibashi and R. Sahara. 1940, *Journ. Chem. Soc. Japan*, 61, 513.

15. On Copper Content in Sea Water and Bittern, by M. Ishibashi, K. Kurata, and T. Hirobe. 1940, *Journ. Chem. Soc. Japan*, 61, 726.

16. Chemical Compositions of Shallow Sea Muds Along Korean Beaches, and Values of Resources, by M. Ishibashi. 1941, *Nipp. Gak. Kyokaishi*, 16, 379.

17. Chemical Studies of Deep Sea Muds in the Pacific Ocean, Parts 1–12, by H. Hamaguchi. 1938, *Journ. Chem. Soc. Japan*, 59, 171.

Summary of Discussion

Dr. Plesch, who presented the Japanese papers on behalf of SCAP, spoke to the meeting about the efficient organization developed for contact with Japanese scientific circles, and liaison with British and American workers. There was, he stated, a very complete tracer service in existence for individual workers and their publications. Semi-annual reports were issued on scientific projects, inquiries on detailed points being referred to the Japanese Ministry of Education. Direct communication with Japanese through the international mails was now possible. Japanese can send publications abroad, or written manuscripts, but, strangely, there is still a restriction on typed manuscripts. The Japanese workers are showing an extreme willingness to exchange papers, in English or with English *résumés*. There is an extensive abstracting service by the Economics and Scientific Section of SCAP, principally through the normal abstracting journals, and scientific institutions in Japan are rapidly resuming outside relations.

The relevant address was given as Economics and Scientific Section, Supreme Command Allied Powers, A.P.O. (U.S. Army) 500, c/o Postmaster, San Francisco.

SYMPOSIUM ON MARINE BIOGEOGRAPHICAL PROVINCES IN THE PACIFIC

SURFACE BOUNDARIES IN THE SOUTHERN OCEAN

By G. E. R. Deacon, Admiralty Research Laboratory, England

[*Abstract*]

More information about the Antarctic Convergence, the boundary between Antarctic and subantarctic waters at the surface, has been obtained by the detailed analysis of thermograph records obtained by the vessels of the " Discovery " Investigations (Mackintosh, 1946). The mean position is little different from that published in 1937, and the new figures strengthen the conclusion (Deacon, 1937) that the position of the surface boundary is closely related to the deep and bottom currents which are subject to little variation. Secondary fluctuations can be attributed to local causes, but it is found that half the reported positions fall within 25 miles of the mean position, and the extreme displacement may not exceed 100 miles. The average difference of temperature is 2° c., from 4° c. to 6° c. in summer, and 1° c. to 3° c. in winter, and if it is less than 2° c. observations of surface temperature alone may not be sufficient to show exactly where the boundary is crossed. Many of the biologists who have examined the " Discovery " collections have remarked on the significance of the convergence as a boundary for species of plankton, fish, and non-abyssal bottom-living animals. Its position is also related to the distribution and stratification of the bottom sediments. R. C. Murphy has given a list of fifteen birds typical of the Antarctic zone, twenty-nine typical of the subantarctic zone, and eleven common to both.

The subtropical convergence between subantarctic and subtropical water is usually marked by a difference of 4 or 5° c., from approximately 12° c. to 16° c. in summer and 8° c. to 12° c. in winter, and the increase in temperature is accompanied by a sharp increase in salinity. It has been found to limit the distribution of some species of plankton, fish, and bottom-living animals. The simplest explanation of the sharp difference in physical properties is that it marks the convergence of water movements with northward and southward components. The boundary is sharpest where a current convergence is most likely, as in the regions south of the Brazil current, Agulhas current, and East Australian current, and it appears to be less sharp in the eastern half of each ocean, where the current in middle latitudes has a more northerly trend. The position of the subtropical convergence appears to be subject to considerable variation, especially in the eastern half of each ocean, and Defant (1938) has suggested that it would be better to describe it as a convergence region rather than a line. This should prove a useful suggestion, though it is likely to prove that the convergence region is one over which a sharp boundary fluctuates, rather than one of gradual change.

Stephenson (1947), dealing with littoral regions, thinks the term " subtropical " misleading when it is applied to water which may be as cold as 12° c. in winter, and prefers the names " warm temperate " and " cold temperate " to subtropical and sub-Antarctic.

LITERATURE

DEACON, G. E. R. (1937): The Hydrology of the Southern Ocean. *Discovery Reports*, 15, 1.

DEFANT, A. (1938): Aufbau und Zirkulation des Atlantischen Ozeans. *Preuss. Akad.d.Wiss. Phys.—Math. Klasse*, XIV.

MACKINTOSH, N. A. (1946): The Atlantic Convervgence and the Distribution of Surface Temperatures in Antarctic Waters. *Discovery Reports*, 23, 179.

STEPHENSON, T. A. (1947): The Constitution of the Intertidal Fauna and Flora of South Africa. Part III. *Annals Natal. Mus.*, 11, 207.

SUMMARY OF DISCUSSION

Dr. Murphy referred to the critical work in New Zealand of Mr. Fleming, on the bird life on either side of the subtropical convergence which divides the two main islands of New Zealand. Mr. Fleming gave an account of his work in 1938 in attempting to apply the oceanographic and sea-birds correlation of Dr. Murphy to the New Zealand region. A strong correlation was obtained, together with some anomalies. With regard to the latter it was intended to reserve them for review in the light of further oceanographic data as this became available.

New Zealand coasts were washed in the Cook Strait region by a belt of mixed waters, which was ornithologically intermediate, having two boundaries, the one at the south being more potent. The littoral marine faunal provinces were well correlated with the oceanographical results to a greater extent than Dr. Deacon had indicated. Powell's faunal provinces were briefly discussed. Wolfgang Schott's work on the stratification of bottom deposits was cited, and from speciation of one New Zealand bird genus (*Pachyptila*) in Pleistocene times, Fleming had postulated a migration of the convergence. The New Zealand situation was complicated by anomalies, probably partly due to inadequate information. A much closer grid of stations was required. Mr. Fleming agreed with Dr. Deacon as to the thrill of passing over the convergence with the accompanying sharp changes in birds and surface fauna. He recalled the appearance of Barracuda on crossing the sub-tropical convergence.

Mr. Powell referred to his investigation of the " Discovery " mollusca, and pointed out that the plotting use of the subantartic and cold temperate zones, as shown on Dr. Deacon's map, was not quite followed.

Dr. Deacon stated that the " Discovery " boundaries fitted in well for subabyssal polyzoa, and pointed out that Stevenson's work was applicable only with shore-dwelling animals. It did associate Macquarie Island with South Georgia, though Kerguelen and Herd Island were placed in the cold temperate. Professor Yonge concluded with the observation that with littoral fauna the air temperature is a factor of equal importance with sea temperature.

PAST HISTORY OF THE DISTRIBUTION OF ANTARCTIC ALGÆ

By C. SKOTTSBERG, Gothenberg, Sweden

[*Abstract*]

The author has tried to compile a list of the truly Antarctic seaweeds occurring along the coast of the continent and adjacent islands. Although South Georgia lies south of the Antarctic convergence it is excluded. This floristically remarkable island is transitional in character.

An overwhelming part of the seaweeds known have been found in the American sector of West Antarctica on the Pacific side. Little is known about the flora of East Antarctica, the most important contribution having been made by " Banzare " expeditions. The author is at present studying this collection, which adds much to our knowledge and contains some undescribed species.

At present we know 12 *Chlorophyceæ*, about 65 *Rhodphyceæ*, and 18 or 19 *Phæophyceæ* from the Antarctic. All groups contain some endemic species, but the bulk is formed by subantarctic forms, of which some are Circumpolar. A remarkable degree of endemism is shown only by the *Phæophyceæ*, with 5 endemic genera, some of which have no close relatives. The arctic flora gives exactly the same impression, but is much richer. This is in accordance with the distribution of land and sea in the north, where the transition from the Subarctic to the Arctic zone is quite gradual. The Antarctic and subantarctic zones are separated by wide expanses of water, probably crossed by dispersal units only on rare occasions and hardly ever in the direction north-south, or *vice versa*, because of the west wind drift. Another reason for the poverty of the Antarctic lies in its history since the beginning of the Ice Age. Life conditions are very severe, as they are now, suitable localities for marine algæ in the intertidal region being of very limited extent because of both the extension of the inland and shelf ice and of the destructive action of the sea ice in motion. During the maximum glaciation conditions must have been much worse, the refuges were few, and only the hardier species survived. During the post-Glacial a gradual reimmigration took place. Even South Georgia was almost entirely ice-covered and its marine flora must have suffered great losses. Nevertheless, it shows a remarkable number of outstanding endemic types. The glaciation did not have the same destructive influence in the Arctic, where the algæ could retreat south along the coasts of both the Altantic and the Pacific.

It is very difficult to get a firm hold on the pre-Glacial history of the Antarctic algæ. They belong to an extreme cold-water flora which, as far as we are able to judge, cannot exist under Temperate conditions. Marine algæ are sensitive in this respect ; they are, all over the globe, distributed in distinct zones of temperature. If we go back to the Tertiary, we soon get to a point where there was no cold water at all. Of course, already during Eocene—and before—climatic zones existed, and they became more pronounced in the Oligocene and Miocene, but the land flora in the Polar regions was more or less subtropical, both south and north, and the seas must have been warm. A source of cold came into existence with the formation of mountain ranges, in the south, the Antarctandes. Here Temperate-montane and Alpine land floras developed. Snow and ice accumulated on the mountains, which were higher than now, glaciers descended into the valleys, and eventually reached sea-level, inaugurating the era when a marine flora, adapted to cold water, was born, the ancestors of the present-day flora, just as the Sub-tropical penguins, found as fossils in old Tertiary strata on the Palmer Peninsula, are the ancestors of the living cold-water penguins. Thus the truly Antarctic marine bios is comparatively recent.

Another factor to be taken into account is the supposed land connections between the Antarctic and subantarctic. They affected the currents profoundly, and circumpolar dispersal was impossible. We face a very complicated problem here, and it will require a lot of thinking to understand the influence of such land connections on the evolution and distribution of plants and animals. Most likely the West Antarctic bridge was sunk during the final upheaval of the Cordillera and the definite cooling of the Polar zone. The connections Enderby-Kerguelen and East Antarctica – Tasmania and New Zealand are more hypothetical, but we cannot explain the biogeography of the subantarctic zone without them.

SUMMARY OF DISCUSSION

Dr. Yonge suggested that the differences pointed out between the Arctic and Antarctic flora in numbers of endemics, might be explained by the fact that Antarctica was itself a continent, while towards the Arctic the northernmost parts of the great continents continue upward.

Dr. Falla wondered whether the tolerances and physical needs of *Macrocystis* were sufficiently narrow to make it a useful indicator genus, as proposed by Dr. Skottsberg. It did not occur, it was answered, in the true antarctic. Dr. Deacon stated he had found it in the South Orkney Islands, and Dr. Skottsberg replied that this was a possibility which would prove very interesting. It was present certainly in South Georgia, but was very small compared with its occurrence at Kerguelen and the Falkland Islands in such thick belts that there was no chance of getting ashore.

Miss Moore pointed out that New Zealand lay across the subtropical convergence. Many algæ, including *Macrocystis*, reach their limit on the North Island coasts, serving to mark diagrammatically the margin of the convergence zone. *Desmarestia* was another case in point. Some northern species, especially on the east coast, are observed to overlap to the south. The Tasmanian algal flora agrees much more closely with our New Zealand North Island than with the South Island flora. This serves again to confirm the inclusion of Tasmania and the North Island of New Zealand within the subtropical convergence.

Professor Chapman raised some further problems which he considered were opened up by Skottsberg's paper. On Wegener's Theory of Continental Drift he (Professor Chapman) and Dr. Skottsberg did not see eye to eye. Professor Chapman still adhered to the continental drift ideas, and had heard no evidence from Dr. Skottsberg's paper to confute that view. Dr. Skottsberg, in discussing the origin of cold-water algæ, had claimed that a point must have been reached in the Tertiary where there was no cold water at all. But to-day, even in subtropical South Africa and California, we do get cold water welling up. The algæ may have evolved in the pre-glacial period and survived in these masses of cold water. Antarctic mud had been shown to underlie the diatomaceous ooze, and if Dr. Skottsberg was correct in thinking that the waters were warmer it would be likely that a further deposit of diatomaceous ooze would underlie the mud. Dr. Skottsberg, in replying, did not underrate the importance of the upwelling of colder waters, but pointed out that each such up-flow must have an original source, which is to-day the Polar ice-cap. No such sources could have existed during the early Tertiary. He agreed, however, that it was hardly possible that the subantarctic cold-water species could have evolved after the Tertiary glaciation. Professor Chapman wondered if the oceanographers could render assistance with the question of past cold-water occurrences. Dr. Deacon thought that little attention had yet been given to the problem raised.

THE POST-MIOCENE EVOLUTION OF MARINE FAUNAS IN THE SOUTH-WEST PACIFIC AND ITS BEARING ON THE PROBLEM OF MARINE FAUNAL PROVINCES

By C. A. Fleming, New Zealand Geological Survey

Persistence of the concept of biogeographical regions implies a considerable degree of agreement between the distribution areas of different groups of organisms. Faunal boundaries based on the distribution of one group are often valid for another group, provided that such groups occupy a common environment and share the same sort of dispersal mechanism. For the marine fauna and flora of the continental slope these conditions hold, so that conclusions based, for instance, on study of mollusca are to a considerable degree valid for echinoderms or marine algæ. By analogy, in studies of historical biogeography we may infer that faunal change in one group was paralleled in others, that the factors controlling invasions, changes in distribution, and extinctions, determined by study of fossils in one phylum, may apply to another phylum which has left little or no fossil record. Few groups of organisms have left as complete a record of their past distribution as have the marine shelled mollusca, and conclusions based on their study may shed light on the faunal evolution of other groups. This hope is offered as excuse for the title of a paper which deals entirely with mollusca.

Generic range charts have been compiled for the New Zealand Pliocene and Pleistocene mollusc fauna, based on collections from the Wanganui area, supplemented by published and unpublished information from other parts of New Zealand. The information was plotted against a time scale (Table 1) divided according to the system of stages used in New Zealand stratigraphy (Finlay and Marwick, 1947). Substages used in the Wanganui series and stages of the Hawera series have been proposed elsewhere (Fleming, in preparation). The boundary between Pliocene and Pleistocene is not certain, so that the local stage system is used in the diagrams that illustrate this paper.

Table 1—Subdivisions of the New Zealand Pliocene and Pleistocene

Series.	Symbol.	Stage.	Substage.	Approximate Correlation.
Hawera..	H2	Oturian ..	..	Pleistocene.
	H1	Puaroan ..	..	
Wanganui	CP	Castlecliffian ..	Putikian ..	..
	CO		Okehuan ..	..
	NM	Nukumaruan	Marahauan ..	(Boundary uncertain.)
	NH		Hautawan ..	
	WM	Waitotaran ..	Mangapanian	Pliocene.
	WW		Waipipian ..	
	O	Opoitian ..	..	..

There are some 490 molluscan genera in the New Zealand Recent fauna for which some fossil record might be expected (shelled marine gastropods, pelecypods, scaphopods). Only about 350 of these have so far been identified as fossils, and lack of knowledge of the remaining

140 is some measure of the imperfection of the geological record. In order to formulate hypotheses concerning the history of the fauna in this study, the actual known occurrences have been taken at their face value; the earliest *record* of a genus is inferred to be its first *appearance* in New Zealand and the absence of a genus after a period of occurrence is taken to indicate its extinction. The arbitrary acceptance of negative evidence implied by this empirical method is unavoidable if we are to generalize at all, but is a warning that such generalization is fallible and liable to revision with improvement of the data on which it is based.

FAUNAL RICHNESS

The total number of genera present in any one stage or substage varies, and may be used as an index of faunal richness (Fig. 1). In the Pliocene, 452 genera occur, and the total present at one time varies from 327 to 354. The early Pliocene faunas (Opoitian and Waipipian) are richer than later ones, and there are two periods of relatively low totals in the Mangapanian-Hautawan and in the Okehuan. Fluctuations in faunal richness are the result of extinctions on the one hand and invasions on the other. The form of the graph suggests that these opposing processes did not operate at random, but that the phases when extinction was the dominant process alternated with phases of invasion.

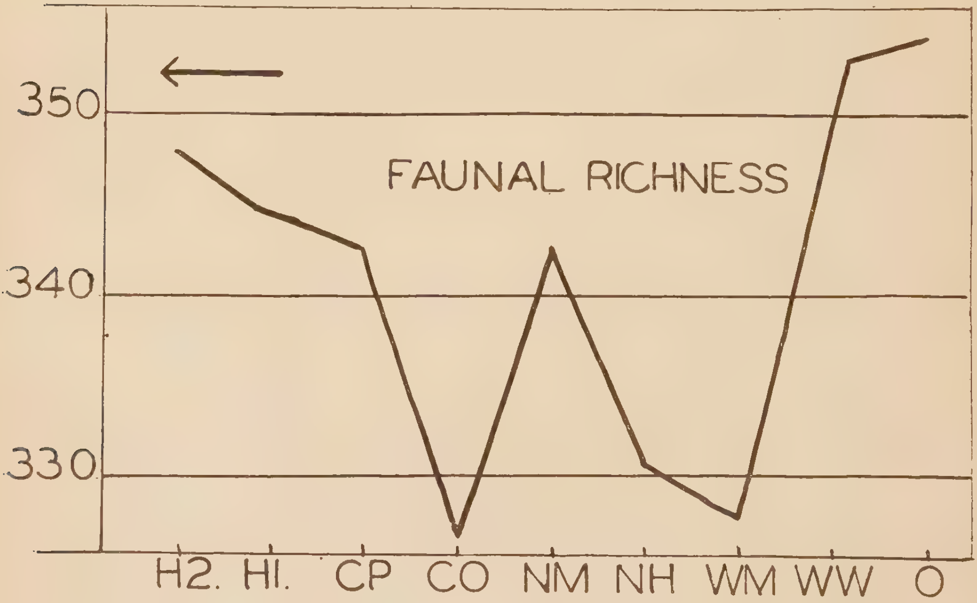


FIG. 1.—Total number of molluscan genera in New Zealand Pliocene and Pleistocene stages, plotted against time scale. For symbols see Table 1

NUMBERS OF IMMIGRANT GENERA AND OF EXTINCTIONS

Figure 2 summarizes what is known of the appearance and disappearance of molluscan genera during post-Miocene time in New Zealand. The total "first appearances" for a given stage or substage

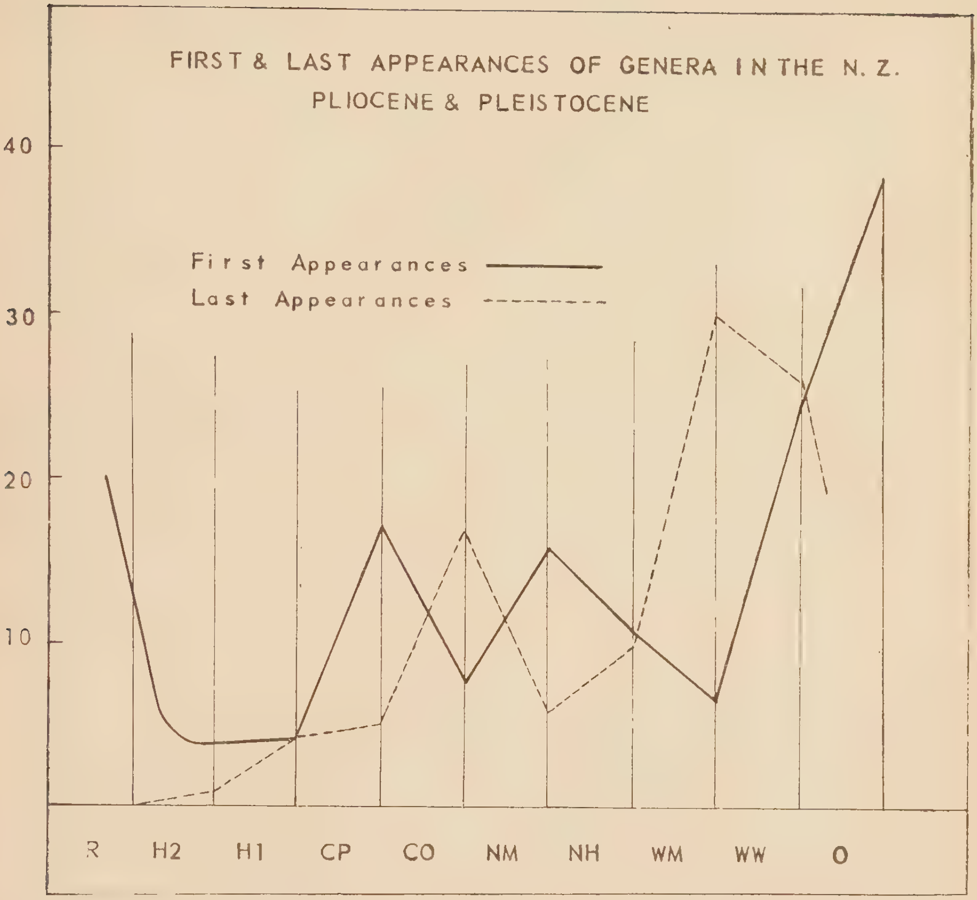


FIG. 2.—First and last appearances of molluscan genera in New Zealand during Pliocene and Pleistocene time

are plotted at the beginning of the interval representing that stage, and " last appearances " at the end of that interval. The marked inverse relationship between first appearances (= invasion) and last appearances (= extinction) is apparent. The times when large numbers of genera appeared were times when few extinctions occurred, and, conversely, when extinctions were numerous invasions were few. The invasion rate dropped steadily until the Mangapanian, had recovered by the Marahauan, dropped again to introduce the Okehuan, and recovered temporarily at the beginning of the Putikian. The extinction rate rose highest in the two " lean periods." Thus the factors which caused the extinction of molluscan genera seem to have also inhibited the invasion of others. Conditions favouring a fairly continuous, though decreasing, invasion of genera were interrupted on at least two occasions by the temporary onset of conditions speeding extinction and substantially slowing invasion.

Affinities of Successive Faunas

The genera of New Zealand mollusca can be readily grouped in four categories depending on whether they are: (1) endemic, (2) common to Australia and New Zealand, (3) distributed through the subantarctic zone of surface water, (4) common to New Zealand and to some part of the great Indopacific Region. More categories would be desirable, but have not proved feasible. In particular, it would be useful to subdivide the group showing Indopacific affinity. Some genera classed as Indopacific are present in Australia and seem to have come to New Zealand from there; others are unknown in Australia and seem to have reached New Zealand by a more direct route from the north. Marwick (1926) long ago stated that "Australian and Indopacific elements have undoubtedly reached New Zealand during the Tertiary." When successive Pliocene and Pleistocene faunas are analysed (Fig. 3) it is apparent that no catastrophic change in the percentage composition of the fauna occurred during the period. The Australian element increased by 5·5 per cent. and the subantarctic element by 1·5 per cent. at the expense of the Endemic and Indopacific. This relative stability of faunal composition is the result of a balance between the opposing factors of extinction and invasion, and suggests that throughout the period the New Zealand fauna shared the same faunal influences, with a slight improvement in contacts with the subantarctic and with Australia.

Derivation of Immigrant Genera

The "first appearances" of mollusc genera since the Miocene are analysed in Fig. 4. The graphs for the four groups of genera fluctuate in sympathy; there is no simple alternation in the affinities and implied derivation of newcomers to the fauna; no period, for instance, when Indopacific "invasion" was replaced by Australian "invasion." (The number of subantarctic genera is too small to warrant generalization.) On the contrary, the several "lean periods" affected immigrants of all groups. There is, however, a marked (if fluctuating) decrease in the number of endemic genera that appear cryptogenetically, and the Indopacific influence, strong at first, is considerably reduced in the middle of the period studied, recovering temporarily in the Putikian substage.

The high number of endemic genera that appear for the first time in the Pliocene deserves comment. For the vast majority of such endemic genera no immediate ancestors are known in New Zealand; our ignorance of some may be due to the imperfection of the record, but, for most, we must infer an origin in some other area, and later immigration to New Zealand seas. The places of origin of such genera may not have been far distant, in the many areas which have supplied no adequate record of their Pliocene fauna, such as eastern Australia, New Caledonia, and other islands to the north, and the Subantarctic.

Oceanographic Changes

That the periods of faunal deterioration noted in the above sections may have been periods of climatic deterioration is a plausible hypothesis and has been invoked by many students to account for post-Miocene extinction of genera. Many of the extinct genera are stenothermal in warm seas where they persist, and many of those which "invaded" New Zealand between the "lean periods" are also warm-water ones.

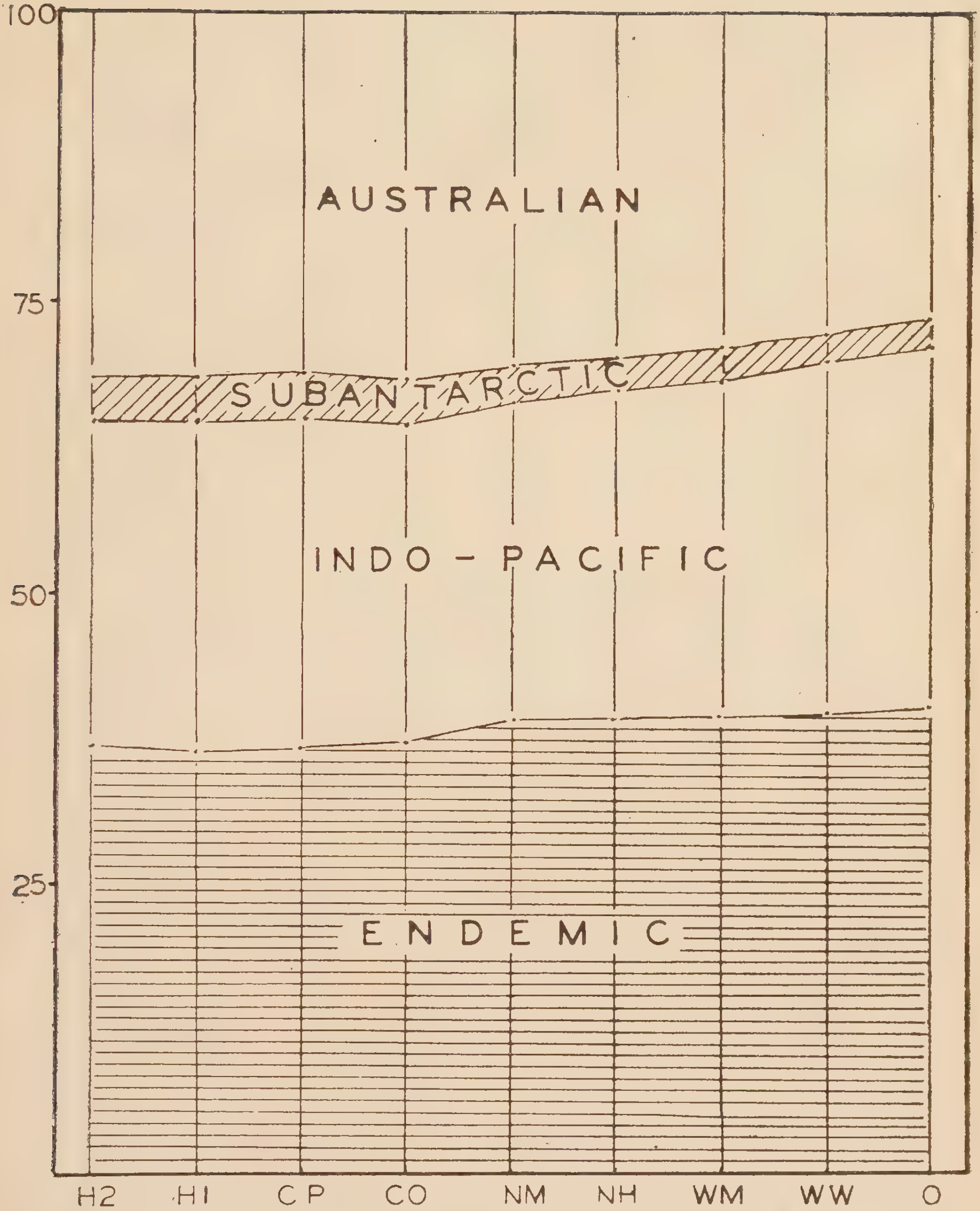


FIG. 3.—Percentage composition of successive Pliocene and Pleistocene Molluscan Faunas

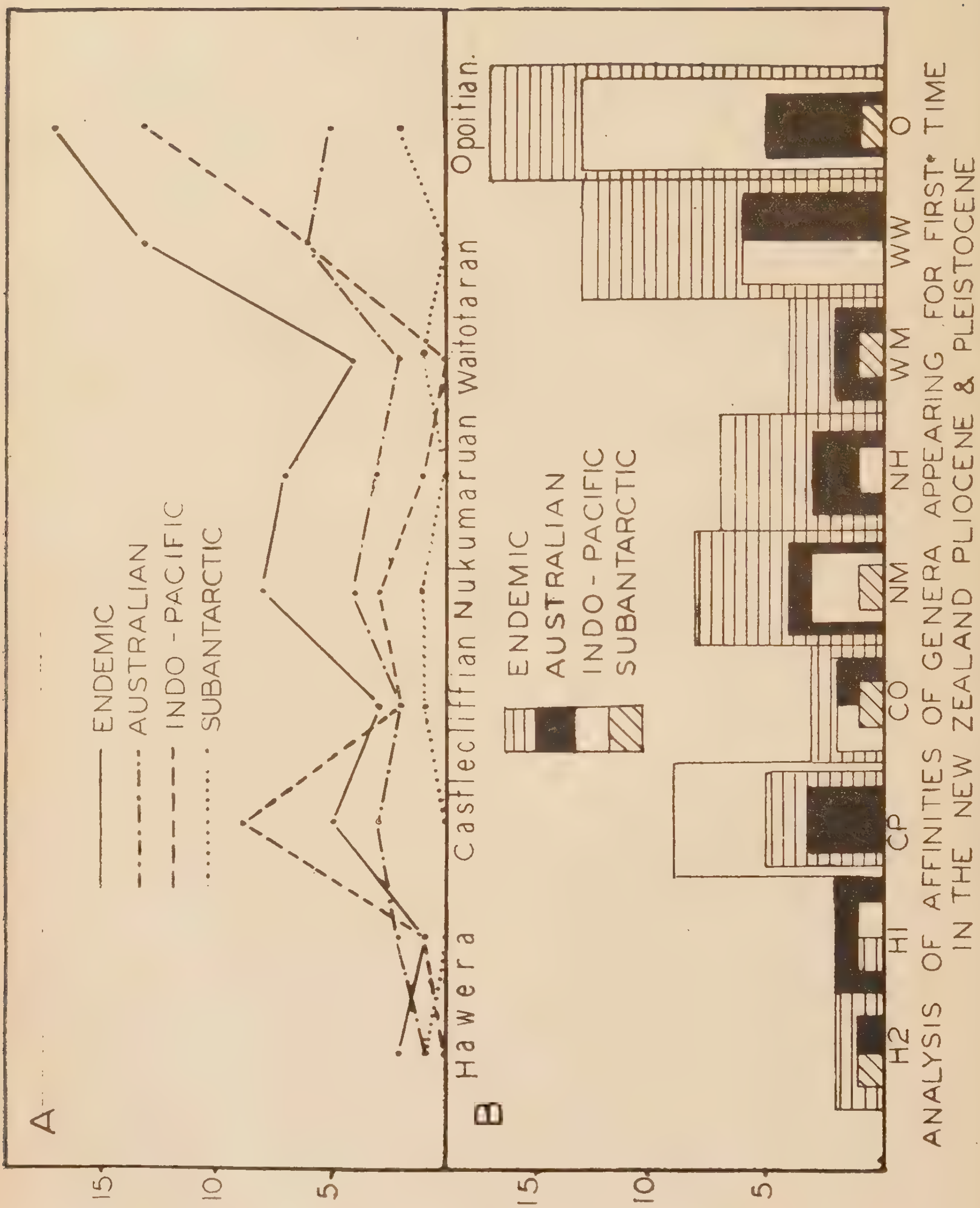


Fig. 4.—(A) Numbers of genera appearing for the first time in successive stages of the New Zealand Pliocene and Pleistocene: Endemic, Australian, Indo-pacific, and subantarctic genera plotted separately. (B) Histogram showing affinities of genera appearing for first time in the New Zealand Pliocene and Pleistocene

The first most acute phase of faunal deterioration coincides with the invasion of a small but significant assemblage of cool-water molluscs (Fleming, 1944) and probably with the earliest recorded glaciation in New Zealand (Gage, 1945). The second (Okehuan) deterioration has not previously been attributed to a cold phase. The two Hawera series faunas certainly fall into a period of time when glacial advances occurred in mountainous areas, but they are from " raised beaches " and thus more likely to be interglacial than glacial (Zeuner, 1946, p. 129).

In periods of oceanic cooling in New Zealand, invasions of subantarctic mollusca could perhaps not counterbalance the extermination of subtropical ones, for the subantarctic fauna is relatively poor in genera and species, and contains a high proportion of rock and kelp inhabiting forms which are seldom preserved as fossils. Many subtropical genera, on the other hand, have vagile pelagic larvæ and live in stations which are preserved, so that the warmer phases of post-Miocene time have left a more distinctive record than the cooler.

FAUNAL PROVINCES

The present Indopacific fauna has sometimes been considered the living representative of the Miocene faunas of temperate seas, just as the mammal fauna of Africa has been dubbed a surviving Pliocene fauna. In the same way past marine faunas in New Zealand have close analogies with contemporary provincial faunas. The time has not yet come for biometric analyses of New Zealand fossil faunas such as have been made in California by Schenck and Keen (1937). Such analyses would establish a probable latitudinal or isothermal equivalent, in Recent times, for a past fauna. The analogies between living and extinct faunas are, however, close enough to suggest a sequence of events illustrated in Fig. 5. This diagram is based on faunal changes in the Cook Strait area, the modern " Cookian Province." The early Pliocene faunas contained genera (such as *Polinices*, *Olivella*, *Cheilea*, *Sinum*, &c.) suggesting conditions more tropical than those of the Aupourian of to-day. The cool water fauna of the Hautawan (Lower Nukumaruan) can be compared with the Forsterian of southern New Zealand, and the succeeding warm faunas of the Marahauan (Upper Nukumaruan) show a return to subtropical conditions (*Pterochelus*, *Ataxocerithium*, *Ellatrivia*, *Isognomon*, &c.). After the second (Okehuan) period of inferred cooling the warm Putikian saw the arrival or return of genera now limited to the Aupourian or even warmer coasts (*Zelippistes*, *Pterochelus*, *Anadara*, *Eunaticina*, &c.). Later faunas are Cookian, but there are a few Aupourian forms in the second Hawera stage. Figure 6 shows in map form the extent of the movements of provincial boundaries implied by the analogies drawn.

It would not be possible to interpret the fossil record in terms of past oceanographic conditions if there were no correlation between environment and fauna, but there are plenty of anomalies. In particular it has been found in Europe as well as New Zealand that newcomers to a fauna, colonizing under the influence of a favourable environment, may survive the following opposite fluctuation, even if this survival entails tolerance of conditions previously intolerable. Such survivals are known in the fossil record, and help to explain the anomalous

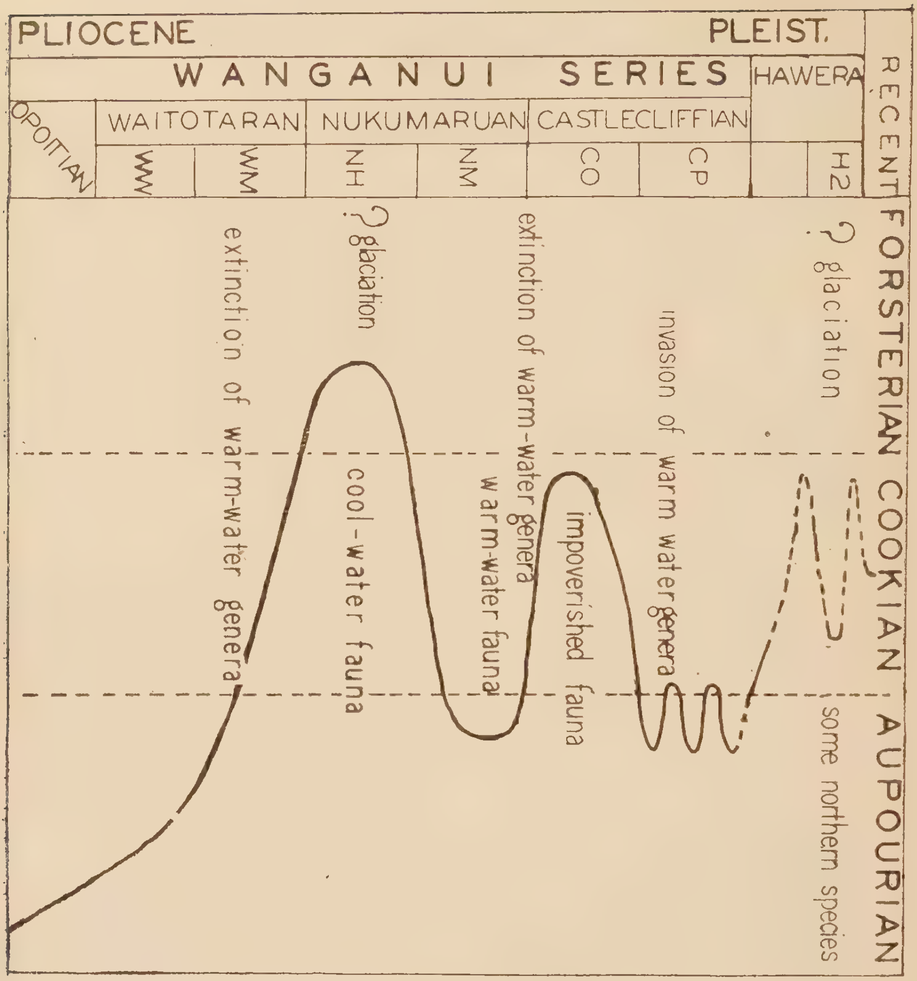


FIG. 5.—Changes in the provincial affinities of successive Pliocene and Pleistocene mollusc faunas near Wanganui

occurrence of, for instance, a group of subantarctic mollusc genera in the subtropical Aupourian Province (Fleming, 1944), and others of subtropical derivation in the subantarctic.

The climatic fluctuations of late Tertiary and Pleistocene time resulted in widespread changes in the distribution of organisms in temperate seas, changes which continued until the threshold of Recent time, and which may still be occurring. The boundaries between the Recent faunal provinces, however defined, must be considered transitory in terms of geologic time. Local faunas owe their constitution to the complex historic processes of immigration, local extinction, and local persistence, controlled in large part by past environmental change. In general, however, local faunal assemblages have persisted longer than the geographical faunal provinces they now inhabit.

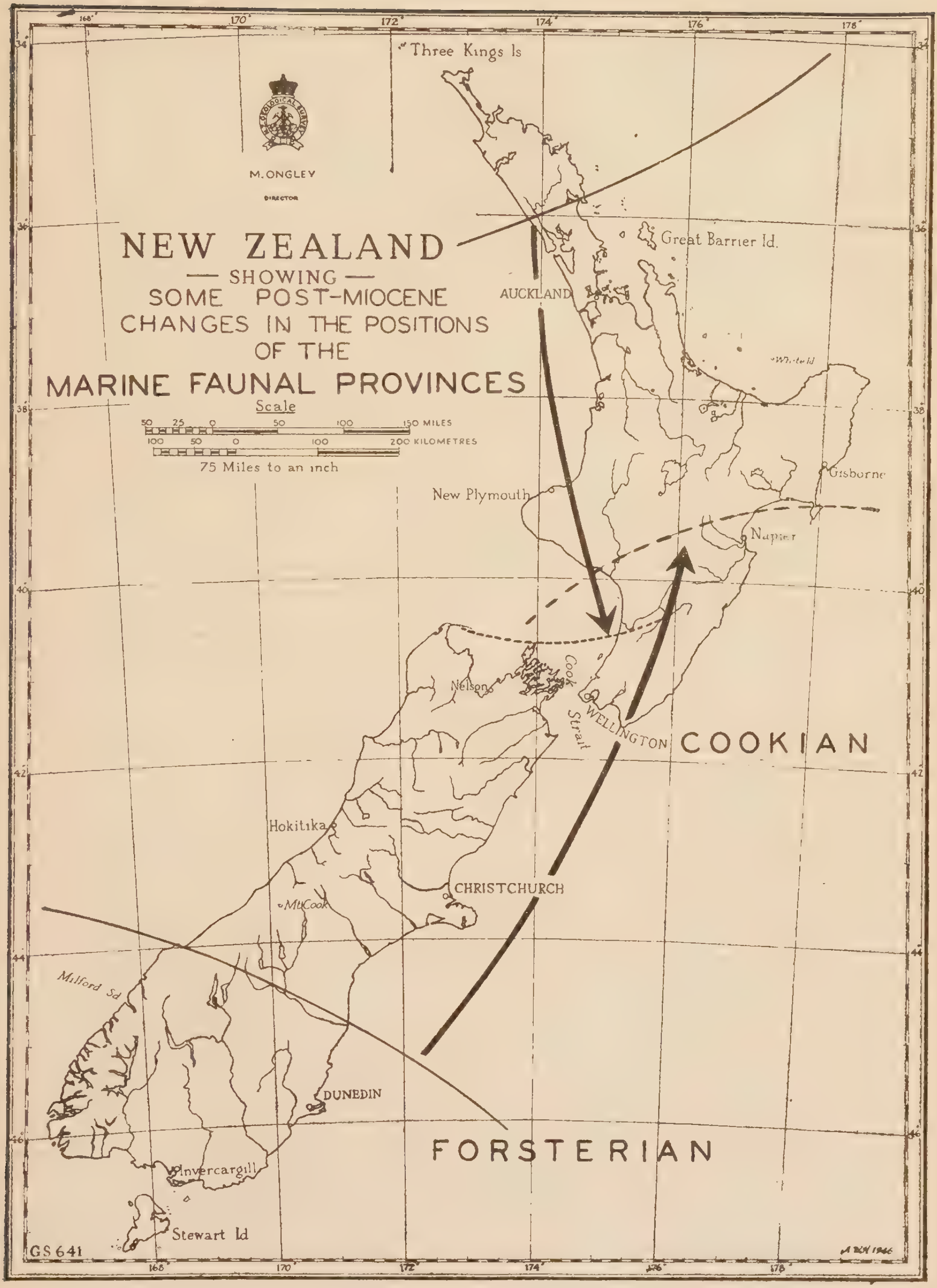

Three Kings Is
M. ONGLEY
DIRECTOR
NEW ZEALAND
SHOWING
SOME POST-MIOCENE
CHANGES IN THE POSITIONS
OF THE
MARINE FAUNAL PROVINCES
Scale
50 25 0 50 100 150 MILES
100 50 0 100 200 KILOMETRES
75 Miles to an inch
Great Barrier Id.
AUCKLAND
White Id
Gisborne
New Plymouth
Napier
Nelson
Cook Strait
WELLINGTON
COOKIAN
Hokitika
CHRISTCHURCH
Mt Cook
Milford Sd
DUNEDIN
FORSTERIAN
Invercargill
Stewart Id
GS 641
168°
170°
172°
174°
176°
178°
34
36
38
40
42
44
46

FIG. 6

REFERENCES

FINLAY, H. J., and MARWICK, J. (1947): New Divisions of the New Zealand Upper Cretaceous and Tertiary. *N.Z. Journ. Sci. Tech.*, Vol. 28, No. 4 (Sec. B), pp. 228–236.

FLEMING, C. A. (1944): Molluscan Evidence of Pliocene Climatic Change in New Zealand. *Trans. Roy. Soc. N.Z.*, Vol. 74, pp. 207–220.

GAGE, M. (1945): The Tertiary and Quarternary Geology of Ross, Westland. *Trans. Roy. Soc. N.Z.*, Vol. 75, pp. 138–159.

MARWICK, J. (1926): The Origin of the Tertiary Mollusca of New Zealand. *N.Z. Journ. Sci. and Tech.*, Vol. 8, No. 5, pp. 269–272.

SCHENCK, H. G., and KEEN, A. M. (1937): An Index Method for Comparing Molluscan Faunules. *Proc. Am. Phil. Soc.*, Vol. 77, No. 2, pp. 161–182.

ZEUNER, F. E. (1946): *Dating the Past, An Introduction to Geochronology.* Methuen and Co., Ltd., London.

SUMMARY OF DISCUSSION

Dr. Yonge pointed out that one of the gaps in the knowledge of the geological distribution is due to our lack of information as to breeding temperatures of the groups in question.

Dr. Kuenen wondered if there was any reason for Mr. Fleming's modesty in disclaiming the development of New Zealand endemic species within the New Zealand region and postulating a yet undiscovered origin elsewhere. Mr. Fleming replied that where a large population suddenly appeared thriving in an area where it had no known ancestors his philosophy of speciation—in which geographical isolation played a major part—would lead him to postulate an invasion from elsewhere. In some cases the New Zealand endemic genera showed affinities with other Indopacific areas rather than New Zealand.

A NOTE ON THE GEOGRAPHICAL DISTRIBUTION OF THE MARINE ANIMALS ALONG THE JAPANESE COAST

By IKUSO HAMAI, Biological Institute, Okazaki Higher Normal School, Toyokawa, Japan

IT is well known that the boreal and tropical, or northern and southern, fauna are mixed in the Japanese coast. The number of animal species and their distribution have been suggestively studied in relation to a quantitative indication of the geographical distribution by Otuka(1) (1936) about the marine Mollusca and by Kuronuma(2) (1942) about the flat fishes. Otuka has used the *coefficient of closeness* to compare the Molluscan fauna between several localities, which is the ratio of the number of common species between two localities to the geometric mean of their respective total number of species, and Kuronuma has given the *latitudinal value* for the flat-fish fauna of a given locality, which is the mean of the latitudinal values of each species, $\{(B - 0) - (4{,}200 - A)\}$, where B and A are respectively the latitudes expressed in minutes at the southern and northern limits of distribution of a species, 0 means the latitude of the Equator, and 4,200 means lat. 70° N. in minutes; therefore, the latitudinal value of a locality shows how much the faunal distribution inclines towards the north or south from the central locality at lat. 35° N. It has been observed that there exist some correlations of the coefficient of closeness or of the latitudinal value with the latitude. Here in this paper a formulation has been attempted in these correlations and an appropriate expression has been given to the mixed geographical distribution of the northern and southern fauna from the relation between the two indices.

---

(1) OTUKA, YANOSUKE (1936): The Faunal Character of the Japanese Pleistocene Marine Mollusca, as Evidence of the Climate Having Become Colder During the Pleistocene in Japan. *Bull. Biogeogr. Soc. Japan*, 6 (16), 165–170.

(2) KURONUMA, KATSUZO (1942): "Latitudinal Value," a Quantitative Indication of Fish Distribution, and Its Application to the Flat Fishes of Japanese Islands. *Bull Biogeogr. Soc. Japan.*, 12 (4), 85–91.

When the coefficient of closeness in the marine Mollusca calculated by Otuka (1936) are plotted against the latitudes, each locality being a centre, in regard to the localities of the Pacific coast, there exists the following relation,

$$\log y = a\,x + b \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where y is the coefficient of closeness, x the latitude, and a and b constants. Putting x_0 to the latitude of the central locality, in which the coefficient of closeness necessarily becomes 1 and $b = -a\,x_0$, accordingly from the above equation (1)

$$\log y = a\,(x - x_0)$$

where $(x - x_0)$ means a latitudinal difference between the central locality and a locality comparable with it, and a means the decreasing rate of $\log y$ with the latitudinal difference. Practically in the Pacific coast the values of a deviates from $\pm 0{\cdot}0602$ to $\pm 0{\cdot}3098$. Among the groups of localities having a respective centre, the uniformity of the mean values of a given by $a = \Sigma\{(\log y)/(x - x_0)\}/\mathrm{N}$, has been tested by the statistical method for small number of observations (1), with the result that no significant difference has been recognized. In the Japanese coast, as it may be considered that the shore-lines are nearly linear along a north-south projection, and that the environments change monotonously with the latitude from north to south, it can be supposed that the values of a are nearly equal if any locality is the centre. Thus, in the above relation (2) $a = \pm 0{\cdot}134$ is obtained, taking the mean of the total values, where the sign (+) is taken in the case southwards from the central locality and (−) northwards.

When $x_0 = 35°$ N.—that is, when Enosima or Misaki and their vicinities are taken as the central locality, the theoretical values of coefficient of closeness drawn at intervals of 0·1 on a map are shown in Fig. 1, from which it can be perceived that the Molluscan fauna in Enosima or Misaki and their vicinities decreases their common species with the distance from these localities to the north or to the south, and the ratio of faunal mixture with these localities can be read from the expression of coefficient of closeness in this map.

The latitudinal value contains a similar conception to the coefficient of closeness, and the flat fishes and Mollusca are the groups bearing a similar ecological type as a kind of bottom fauna, and therefore a parallel relation is expected between the two indices. Then, the distribution of points as shown in Fig. 2 are obtained when the latitudinal values of the flat fishes in every locality calculated by Kuronuma are plotted against

---

(1) In this paper the statistical methods have been followed by MASUYAMA, MOTOSABURO—1943: Syôsûrei no Matomekata to Zikkenkeikaku no Tatekata (Statistical Methods for Small Observations and Design of Experiments), Tokyo, and Tôkeikagaku-kenkyukai (*Society of Statistical Science Research*); 1943: Tôkeisûtihyô I (Statistical Numerical Tables I), Tokyo.

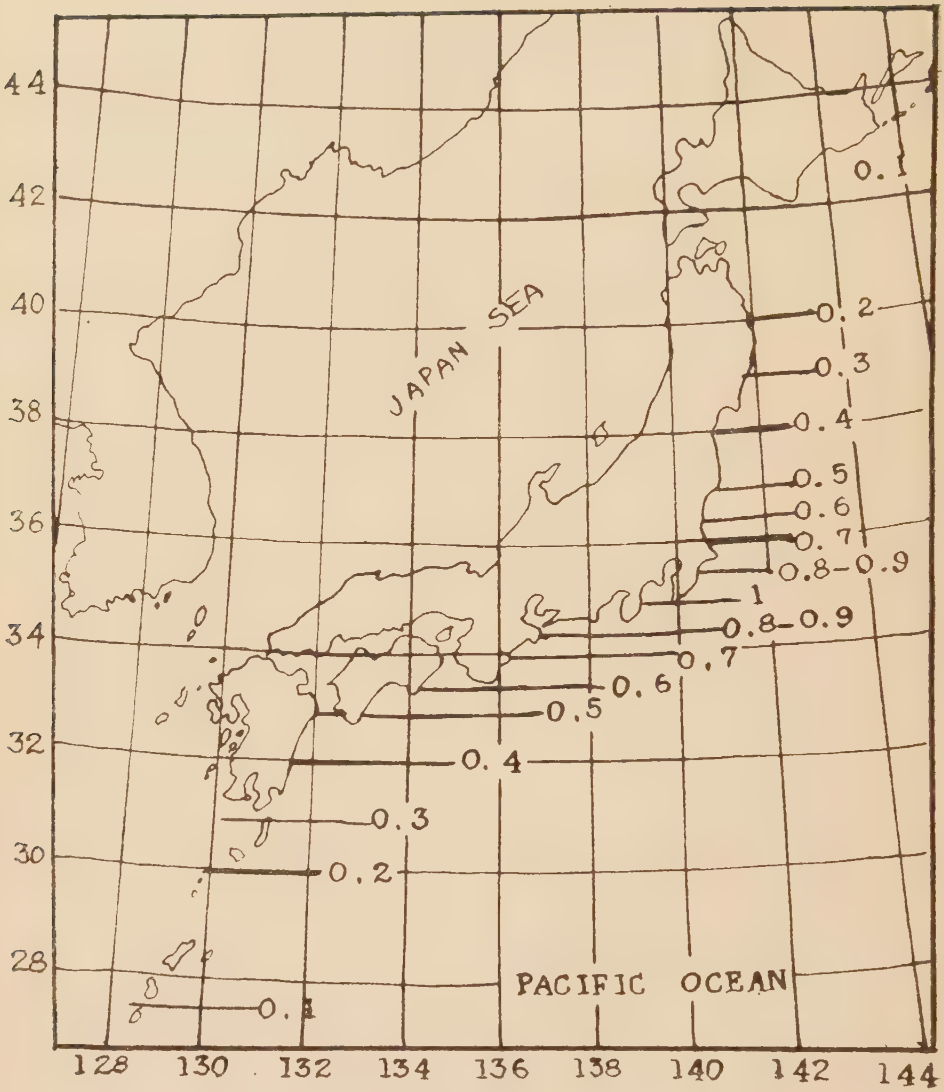

44
42
40
38
36
34
32
30
28
JAPAN SEA
PACIFIC OCEAN
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8-0.9
1
0.8-0.9
0.7
0.6
0.5
0.4
0.3
0.2
0.1
128
130
132
134
136
138
140
142
144

FIG. 1.—The distribution of the coefficient of closeness in the Pacific Coast

the theoretical values of the coefficients of closeness of Mollusca calculated by the equation, $\log y = \pm 0 \cdot 134\ (x - 35)$, taking the localities northwards from lat. 35° N. on (+) side and southwards on (—) side. The values of *a* in the coast of the Japan Sea are difficult to decide because of less observations, but the coefficients of closeness have been calculated by using the same value of *a* as that in the Pacific Coast, supposing no difference in both coasts from the point of fact that the observed values in Toyama and Hukui are nearly the same as those at the same latitude in the Pacific Coast. As the points of Soya, Iturup Island, and Hukuoka

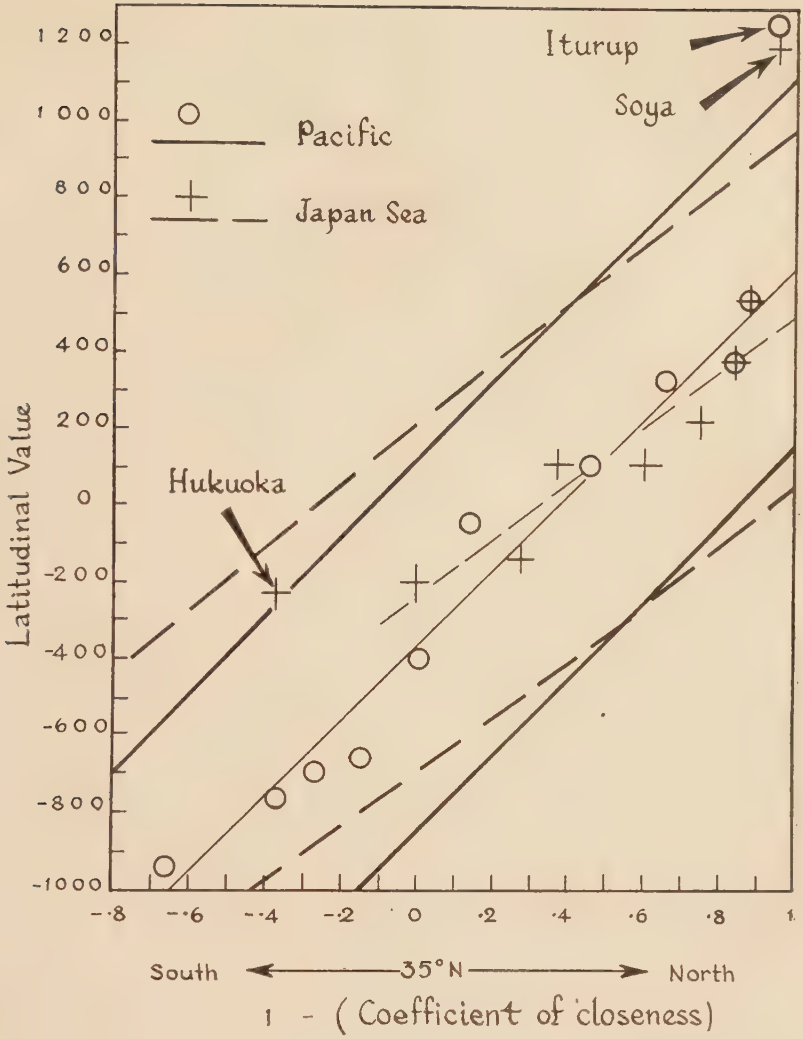


FIG. 2.

FIG. 2.—Correlation between the coefficient of closeness and the latitudinal value, and the rejection-ellipses distinguishing the type of distribution. Thick lines, rejection-ellipses ; thin lines, regression lines

were far apart from the other points, they were excepted from both the Pacific and the Japan Sea groups, and as Hakodate and Aomori should be clearly influenced by both seas these points were together classed in each group. Thus a straight regression would be expected in each group ; therefore the coefficients of regression were calculated as 9·98 in the Pacific Coast and 7·25 in the Japan Sea. Between these two figures no significant difference was recognized from these data under the level of significance of 0·01 available.

Furthermore, supposing the group of these observational points as a random sample taken out from the normal population of two variables, the rejection-ellipse(1) has been drawn at the level of significance of 0·01. By means of the rejection-ellipses differences of the type of correlation of the two indices have been tested between the Pacific and the Japan Sea coasts, and further it has been also tested whether Soya, Iturup Island, and Hukuoka belong to another type or not—that is, points fallen outside of the ellipse are distinguished from the type at the level of significance of 0·01. Thus it has been observed that the values of Soya and Iturup Island belong neither to the type of the Pacific Coast nor to that of the Japan Sea, that Hukuoka is distinguished from the type of the Pacific Coast but not from the Japan Sea, and that between both types of the Pacific and the Japan Sea there exists no significant difference. Then the correlation between the distributions of the latitudinal values in the flat fishes and of the coefficients of closeness in mollusca probably shows no significant difference as well in the Pacific Coast as in that of the Japan Sea ; in other words, the mode of distribution of species in the flat fishes are parallel to that in Mollusca, but in the localities of Soya and Iturup Island the type of fauna is distinguished from that in which the distribution of species gradually changes with the latitude, mixing the northern and southern fauna in the Japanese coasts having the centre at lat. 35° N.—that is, at the latitudes of these localities the fauna contains scarcely southern forms ; therefore, it may be estimated that the northern limit of distribution of this type is lat. 43–44° N. and oppositely the southern limit is lat. 26–27° N.

It has been said biogeographically that the Japanese coast extends over the Boreal Pacific Province and the Tropical Indopacific Province, but their boundary is not so clear. This fact is natural from the view-point of coefficient of closeness, and rather the boundary must be made by the statistical conception. From this point of view the northern limit discussed above as that of the type of the main Japanese coasts may be just equivalent to the boundary between both Provinces.

Nomura and Hatai(2) (1936) have divided Japanese seas into seven provinces from the point of distribution mainly in Mollusca and Brachiopoda. When northern and southern limits of distribution of species exist in a definite range it is possible to find out several species characterizing each province, but the distributions of many species deviate little by little from the definite range and extend over the imaginary biogeographical provinces, and therefore it is unnatural to set up a province only from the characteristic species in that range. Accordingly the biogeographical division is subject to an expediential boundary. The division can be expressed rather strictly in terms of the coefficient of closeness than by the border-lines. In order to discuss the biogeographical distribution it is rather necessary to take account of the gradual decrease in the number of common species from locality to locality or with the distance expressed in terms of the latitude, by means of the coefficient of closeness.

---

(1) Masuyama, M. (1943) : *loc. cit.*

(2) Nomura, Sitihei and Hatai, Kotora (1936) : A Note on the Zoological Provinces in the Japanese Seas. *Bull. Biogeogr. Soc. Japan*, 6 (21), 207–214.

SUMMARY AND CONCLUSION

(1) The coefficient of closeness (y) of marine Mullusca is connected with the latitude (x) in the following equation,

$$\log y = a\,x + b,$$

where a and b are constants. When a given locality is taken as a centre,

$$\log y = a\,(x - x_0),$$

where x_0 is the latitude at the central locality, and a is defined as a decreasing constant of common species. Practically in the Pacific Coast $a = \pm 0{\cdot}134$, being (+) for southern localities and (—) for northern localities from the centre.

(2) The latitudinal value in the flat fishes is parallel to the coefficient of closeness in marine Mollusca, and these animal groups have a common ecological type ; from these facts a similar mode of geographical distribution are reasoned in these animal groups.

(3) The type of distribution shows no significant difference between the Pacific and the Japan Sea coasts, and Soya and Iturup Island are distinguished from this type. From these facts it is estimated that the northern limit of this type of distribution is lat. 43–44° N. and the southern limit is lat. 26–27° N. in the Japanese coasts having the centre at lat. 35° N.

(4) The coefficient of closeness and the latitudinal value are respectively a characteristic index to show a faunistic change from locality to locality ; however, the former is rather superior to the latter in respects of possibility to compare the difference among localities and to estimate the type of geographical distribution, in the case of which the northern and southern limits are difficult to decide in the geographical distribution of animals. And, further, the expression of decrease of the coefficient of closeness from the centre to distant localities is superior to that of geographical division into provinces expediently by reason of the distribution of several characteristic species.

SYMPOSIUM ON PROBLEMS OF BIPOLARITY AND OF PAN-TEMPERATE FAUNAS

ANTITROPICAL DISTRIBUTION OF FISHES AND OTHER ORGANISMS(¹)

By CARL L. HUBBS, Scripps Institution of Oceanography, University of California

WHEN naturalists travel from their home lands and waters in the North Temperate Zone to South Temperate regions, as many of us recently have, they are struck first by the bewildering abundance of strange life in the tropics and are then impressed, as they enter the refreshingly cooler regions still farther southward, by the reappearance of certain familiar types of plants and animals. True, these forms are mixed with strange organisms, but it is the familiar ones that engender the depth of feeling that comes with the reunion of old friends.

Since it first attracted the attention of travellers from Europe to far southern lands this phenomenon has been called " bipolar distribution " or " bipolarity," and has been variously explained. One of the theories, that of separate creation, might now be modified into one of independent adaptive evolution. Another idea has been that the similar forms of north and of south are relicts, which stemmed from a cosmopolitan biota of an early Tertiary period of relatively warm and uniform world climate. On this theory the disjunct populations were forced apart by the increasing heat of the Tropics and by competition with a recently evolved rich tropical biota. Still another concept is that the Tropics have been crossed and to some extent are still being crossed, along isothermal lines, the marine forms dipping into the cold deep sea and the land forms rising to cold mountain heights. Advocates of continental drift have found in their aberrant hypothesis an explanation of bipolarity, as well as of almost every other phenomenon of biogeography.

A more recent and in general more plausible explanation, stressed by Berg (1933), is that the Tropical waters were transgressed during the Pleistocene periods of global cooling. This is the theory to which I particularly subscribe, though I recognize that each alternative explanation mentioned (with the exception of local creation) could be supported by an impressive array of evidence and has probably been valid to some degree for some groups.

In line with this theory of Pleistocene interchange of faunas across the Equator we find, on examining a large body of evidence, that the phenomenon with which we are dealing is only in a very small degree one of bipolarity. As Berg (1933) stressed, the vast majority of the related forms of life that occur on either side of the Tropic Zone, but not within it, inhabit moderate rather than high latitudes. Among marine fishes, as Norman (1938) showed, the Antarctic contains only a small percentage of groups or of species of Arctic relationship. A few forms may be cited as definite examples of truly bipolar distribution ; a much larger number may better be called biboreal or bitemperate, and those that are bitemperate are warm-temperate as well as cool-temperate. Furthermore, a

---

(¹) Contributions from the Scripps Institution of Oceanography.

considerable number of subtropical types are more or less completely separated by the tropical biotas. The phenomenon with which we are dealing is not one of special resemblances between polar elements, but rather one of narrow to broad, incomplete to complete equatorial discontinuities in the latitudinal distribution of plants and animals. It therefore seems desirable that we stop expressing ourselves and thinking in terms of " bipolar distribution " and that we adopt another term—I suggest " antitropical "—to apply to the forms of life that shun the Tropics (the term to apply also to this type of distribution). " Bipolarity " would then become " antitropicality."

There are many patterns of antitropical distribution, because resemblances exist between polar, boreal, cool-temperate, warm-temperate, and even subtropical forms of life ; because the breaks occur along all the main coast-lines that cross the Tropics ; and because the many bitemperate complexes embrace various combinations of two or more temperate biotas (perhaps less than half of the bitemperate series could rightly be classed in the " pantemperate " category, to which I have occasionally referred). These various patterns could be illustrated by different groups of organisms, but I shall largely restrict my discussion to the marine fishes, with which I am most familiar.

The bipolar pattern, as already indicated, involves relatively few fishes. In the Antarctic and subantarctic regions there occur, mixed with a much larger number of endemic types, a few species of families that are otherwise chiefly of Arctic or subarctic range—slime-eels (*Myxine*), skates (*Raja*), and hakes (*Merluccius*) ; also certain cods (Gadidæ), sculpins (Cottidæ), lump-fishes (Cyclopteridæ), snail-fishes (Liparididæ), seapoachers (Agonidæ), and eelpouts (Zoarcidæ and Lycodapodidæ) (Norman, 1937, 1938). In the far south there are several species of *Raja* and a moderate number of zoarcids, but the other bipolar groups are each represented there by only one or a very few species. These Antarctic and subantarctic types seem to have been derived from the far north, where the same groups are much better developed. Most, perhaps all, were probably derived by isothermal dispersal, perhaps in part during Pleistocene periods when lesser depths would probably have been required in the transgression of the Tropics. The tropical crossings were probably chiefly effected along the western shores of the two great oceans. Indeed, as a result of the exploration of the United States Fish Commission vessel " Albatross," Garman (1899) disclosed in the region of Panamà living deep-sea representatives of half the fish groups here listed as bipolar—namely, *Myxine*, *Raja*, *Merluccius*, Liparididæ, and Zoarcidæ. Some of the bipolar fish sets may retain an isothermal connection, as certain invertebrates almost surely do. The varying degree of differentiation displayed by the Antarctic representatives of far northern groups bespeaks widely different periods of isolation. The evidence of relationships and of paleichthyology, however, argues against the pre-Tertiary transtropical dispersal of the groups named above.

Several subantarctic or south-boreal fishes commonly included in the " bipolar " category appear, in contrast, to be ancient, probably pre-Tertiary relicts of groups that have failed to persist in the Tropics, either because of unfavourable physical conditions or because they were unable to compete with the rich faunas that have evolved there. In this category I would include, among fishes, the following fluviatile, anadromous, and catadromous types: (1) the southern lampreys, comprising the genera *Mordacia* and *Geotria*, each referable to a family distinct from the Holarctic Petromyzontidæ, and the distinctive and primitive teleost families Galaxiidæ, Aplochitonidæ, Retropinnidæ, and Prototroctidæ. Their trenchant separation from not clearly recognizable Holarctic representatives indicates prolonged isolation.

A few other primitive teleosts, notably the subantarctic herrings usually retained in the genus *Clupea*, may be pre-Tertiary or early Pleistocene relicts, for they are of ancient lineage. Their degree of differentiation and their far-southern habitat suggest isolation since one of the earlier, intense periods of Pleistocene glaciation.

Bitemperate fish types not only outnumber the bipolar, but also, as a rule, exhibit less differentiation and appear to have had their populations disrupted by tropical waters for a briefer period. The species that exhibit no measured differences on the two sides of the Tropics and those that are only incipiently or weakly differentiated have probably been segregated into northern and southern populations only since late Pleistocene.

Many of the bitemperate types—and among these we might better include some of those here listed among the bipolar—may have crossed the Tropics, perhaps chiefly in Pleistocene times, by descending into deeper water. This is particularly probable for various more or less strictly bitemperate types of sharks, including the genera *Hexanchus*, *Heptranchias*, *Notorhynchus*, *Heterodontus*, *Cephaloscyllium*, some other scyliorhinids, *Galeorhinus*, *Mitsukurina*, *Carcharias*, *Lamna*, *Tetroras* [*Cetorhinus*], *Somniosus*, and *Echinorhinus*, and certain species-groups of *Mustelus* and *Squalus*. Other bitemperate fish types that may have transgressed the Tropics by a deep-water isothermal route during the Pleistocene are the hagfish genera *Eptatretus* and *Polistotrema*; the john-dory (*Zeus*), an example of wide-spread Old World antitropical distribution; also, in the Eastern Hemisphere, various gurnards (Triglidæ), sinistral flatfishes (Bothidæ), and other groups; in the eastern Pacific, such genera as *Cheilotrema*, *Pimelometopon*, *Caulolatilus*, and *Sicyogaster*; the scorpænid genus *Sebastodes*, a speciose North Pacific genus of which one species group has populated waters from Peru to Cape of Good Hope; *Oplegnathus*; and certain clinids.

Many other antitropical fishes of the Temperate Zones, including most of the pantemperate types, have attributes that lead us to believe that they crossed the Tropics when the surface waters were considerably cooled, presumably during late Pleistocene time. Ecologically, they are surface-bound; therefore incapable of transgressing equatorial water by the cool deep-water route. That they crossed the Tropics during the last cold period of the Pleistocene is suggested by their incipient speciation.

In this category of surface-bound recent transgressors of the Tropics we must include such shore-pelagic fishes as the sardine or pilchard genus *Sardinops* (of California, Japan, Peru and Chile, Australia and New Zealand, and South Africa); the roundherrings of the genus *Etrumeus* (of the western North Atlantic, California, Hawaii, Japan, Australia, and South Africa); the anchovy genus *Engraulis* (of Europe, Japan, South Africa, and Australia and New Zealand); the similar anchovies of

California, Peru and Chile, and Argentina, which, as I shall presently show, constitute a distinct genus; the even more strikingly pantemperate jackmackerel (*Trachurus*) and chub mackerel (*Pneumatophorus*) groups; the saury genus *Scomberesox* (of North Atlantic and South Temperate waters); the species of *Seriola* related to *S. dorsalis*; *Centrolophus*; several tunas (Thunnidæ) and tuna-like fishes; also *Alepisaurus* and various other rather pelagic types.

As emphasized by Berg (1933), not only these fishes, but also various other organisms almost certainly had a surface-water connection between the northern and southern hemispheres at a geologically very recent time, very probably, in large part, during the last period of continental glaciation. Notable examples are sealions (Otariidæ), right whales (*Eubalaena*), and the giant kelp *Macrocystis*, which is said to be represented in both hemispheres by the same two ecotypic varieties of a single species.

Zoögeographical, paleontological, and oceanographical data keep accumulating to force the conclusion that the last period of glaciation was synchronous in the two hemispheres and that the isotherms of sea and land were then markedly displaced equatorward. The increased winds from polar toward equatorial regions must have accentuated the convergence of the cool currents, along the eastern shores of the two great oceans. The tropical belt must have been narrowed and considerably cooled everywhere. Paleontological data from Europe and Africa, the occurrence of a land-locked salmon (*Oncorhynchus*) in Formosa, and the ichthyological data in the following paragraphs are samples of the evidence on which these statements rest.

The paucity of the Panamanian marine fish fauna, particularly among the reef fishes, suggests widespread extermination by a marked cooling of the tropical eastern Pacific. This fauna is outstandingly rich only in certain families that characteristically inhabit mud and sand bottom, notably the drums (Sciaenidæ), marine catfishes (Ariidæ), and anchovies (Engraulididæ). A decimated reef fauna would nicely explain the obviously very recent establishment on the tropical American Pacific Coast, particularly on the outlying islands, of Indo-Pacific fishes. The broad intervening expanse of open water, stressed by Ekman (1935) as the most notable barrier in the circumtropical distribution of life, has no doubt allowed only rare strays to reach America from Oceania. Had they reached shores as saturated with life as are those of the Indo-Pacific area it is hardly conceivable that these strays could have established populations.

The former cooling of now essentially tropical waters, about the Cape region of Baja California, is indicated by the entrapment, in the upper part of the Gulf of California, of a rather large faunal element related to that of north-western Baja California and southern California. Most of the constituent types are no longer able to round the tip of the peninsula. The varying differentiation of the Gulf representatives, generally very slight and still unmeasured for some species, suggests the origin of these upper-Gulf types during several periods of Pleistocene global cooling, but chiefly during the last ice period. Somewhat similarly, the occurence in the Galápagos Islands of many Temperate Peruvian types, in part more or less differentiated, suggests transfer and establishment during Pleistocene periods of general oceanic cooling.

The occurrence of European types in South Africa, undifferentiated or weakly differentiated, and of Japanese types not only in South Africa but also in Australia, in similar stages of speciation, suggests that the Pleistocene cooling of the oceans was world wide. Even the vast Indo-Pacific area appears to have been cooled sufficiently to permit the passage of a limited representation of the warm-temperate fauna, though insufficient to exterminate any considerable part of " the great mother fish fauna of the world."

Combining certain zoogeographical and oceanographic data, and accepting the strong evidence that the temperature relations of organisms are very conservative, we may infer the approximate amount to which certain tropical waters were cooled during the late Pleistocene, to allow the transgression of the Tropics by such fishes and other organisms. The evidence is particularly strong and uncomplicated for the long and nearly straight shore of the eastern Pacific, where, it is commonly assumed, the cool-water faunal connections were especially numerous. Along this coast many of the now disrupted forms, such as the sardine and the giant kelp, are separated by a tropic belt that extends from near Cape San Lucas (the tip of Baja California) to the northern limit of the Humboldt or Peru current, in Peru. The almost certainly late Pleistocene faunal connection between these present limits would, we may assume, have required the cooling of the ocean surface to approximately the temperature now prevailing in the region from Cape San Lazaro to Cape San Lucas—that is, off Magdalena Bay, Baja California. The surface temperature data averaged monthly for coastwise squares of 5° latitude and longitude indicate for this region a fluctuation from about 18° c. in the spring to about 25° in the summer, and for the warmest area intervening between this region and the sharp gradient in Peru, a change from 26·5° in the winter to 28° in May. The difference between the monthly averages is about 8·5° for the coldest month and 3° for the warmest. Since, toward the warm end of their ranges, most cool-water forms breed in the coolest season, it is probable that during winter in the last Ice Age the surface of the shore waters of the eastern Pacific was cooled in the order of 8°, though not necessarily more than about 3° during the warmest month. That there was some cooling during the summer is suggested not only by the general data, but also by such facts as this: that the tuna clippers are unable to keep sardines alive at temperatures much above 26°. The decrease of about 8° in winter would account for the presumed annihilation during the late Pleistocene of much of the fish life of the Panamanian region, but not of all the fauna, for there is a large tropical representation about Magdalena Bay, where winter temperatures run low.

Similar, though less definite, data for the western Pacific indicate that the equatorial waters there were cooled during the Pleistocene, but probably not more than 2° to 4° during any month. There is little evidence of extensive cooling of the western Atlantic Tropics during the Pleistocene, but in all probability the convergence of the isotherms and the equatorial cooling was very pronounced along the eastern shores of the Atlantic.

LITERATURE CITED

BERG, LEO S. (1933): Die bipolare Verbreitung der Organismen und die Eiszeit. *Zoogeographica*, 1, 444–484.

EKMAN, SVEN (1935): *Tiergeographie des Meeres.* Akademische Verlagsgesellschaft, Leipzig. 542 pp., illustr.

GARMAN, SAMUEL (1899): Reports on an Exploration Off the West Coast of Mexico, Central and South America, and Off the Galapagos Islands, in Charge of Alexander Agassiz, by the U.S. Fish Commission Steamer "Albatross," During 1891, Lieut. Commander Z. L. Tanner, U.S.N., commanding—XXVI: The Fishes. *Mem. Mus. Comp. Zool. Havard Coll.*, 24, 1–431, 99 pls.

NORMAN, J. R. (1937): Coast Fishes—Part II: The Patagonian Region (Including the Straits of Magellan and the Falkland Islands). *Discovery Repts.*, 16, 1–150, figs. 1–76, pls. 1–5.

—— (1938): Coast Fishes—Part III: The Antarctic Zone. *Ibid.*, 18, 1–105, pl. 1.

SUMMARY OF DISCUSSION

Professor Yonge cited as an example of the ease with which temperate forms traverse tropical regions, the recent appearance of the New Zealand barnacle *Elminius modestus* in docks in Britain. Further, he inquired whether a full analysis had yet been published of the situation in the upper part of the Gulf of California where an isolated population is locked in, corresponding to that of the same latitude outside, but differing from that at the opening of the gulf. An analysis was still being made and would shortly appear in published form, it was stated.

Dr. Johnson mentioned the extraordinary case of barnacles being transported overland to the Salt Lake of Utah. Mr. Powell stated that Dr. Hubbs had very conclusively answered the question to be raised by him in his paper following, as to whether some bipolar animals may or may not go deep in the tropics and as to routes of convergence followed between north and south.

CERTAIN BIPOLAR ELEMENTS IN MARINE MOLLUSCS

By A. W. B. POWELL, Auckland Institute and Museum

[*Abstract*]

These notes are extracted from a report in preparation on the Antarctic and subantarctic Mollusca collected by the "Discovery" Committee expeditions during the years 1926 to 1937.*

The material studied is largely from the American Quadrant. It seems evident that—

(*a*) The greater part of the southern high latitude molluscs have been derived per the American Quadrant; and

(*b*) That the route was, and still remains, the continuity of the west coast of the Americas plus the "Scotia Arc" bridge to Graham Land and for certain deep-water genera the Atlantic-Indian Ocean Cross Ridge which extends eastwards between the Argentine Basin and the Atlantic Antarctic Basin, almost to the Kerguelen-Gaussberg (radial) ridge.

Three gasteropod genera—*Aforia*, *Fusitriton*, and *Acanthina*—are instanced.

---

* A. W. B. Powell, 1951, Discovery Reports, Vol. 26, pp. 47–196

The turrid *Aforia* is a splendid example of a bipolar genus that "goes deep" over the warm zones, *i.e.*—

A. okhotskensis, 50°–60° N.: 73 fathoms; bottom temperature, 30·9° F.
A. persimilis, 1° N.: 741 fathoms; bottom temperature, 38·4° F.
A. magnifica, 64° S.: 152 fathoms; bottom temperature, 32·38° F.

Certain littoral genera, *Liriola* (Northern) and *Kerguelenella* (Southern) are closely related, but no longer have a connected range. They have not "gone deep," which raises the question, were the cold water faunas of both hemispheres sufficiently close during periods of Pleistocene glaciation to allow of interchange of species?

SUMMARY OF DISCUSSION

Dr. Hubbs commented on the peculiar pattern of avoidance of the Antarctic Continent claimed by Mr. Powell in the three genera discussed, and asked whether that might not represent polar extinction, rather than invoke the use of a series of land-bridges. In answer it was pointed out that there is no evidence on the Antarctic Continent of forms related to the three under discussion (two of which are deep water), and that the alleged land-bridge mentioned is actually a ridge at a depth of 2,000 metres. This ridge, or series of ridges, may have been much shallower during an earlier period.

SYMPOSIUM ON PROBLEMS OF EUSTATISM IN THE PACIFIC BASIN AND RIM

SUBMARINE CANYONS IN THE PACIFIC AND THEIR BEARING ON EUSTATISM

By Francis P. Shepard, Scripps Institution of Oceanography, University of California

[*Abstract*]

The submarine slopes along the margins of the Pacific are creased with numerous submarine canyons. Recently the canyons have also been discovered outside the deeply eroded portions of the Hawaiian Islands. Depths of half a mile or more are found in the outer portions of these canyons. Investigations of typical submarine canyons in the California area have been made by bottom sampling, submarine photography, and by diving operations. The results of these studies have shown that the canyons have characteristics which are exact duplications of typical land canyons. Many of the submarine canyons are known to be direct continuations of river valleys on land.

Since all oceanographic data obtained to date serve to show the virtual impossibility that the canyons could have been formed by any other process than river erosion it becomes evident that widespread submergence must have taken place. If this has been the case it should also be indicated by other lines of evidence. Recent soundings show that there are flat-topped seamounts in many parts of the Pacific. These have depths varying from a few hundred to more than a thousand fathoms. The flatness is indicative of wave-bevelling when the submerged mountains stood much higher in relation to sea-level. The discovery of rounded cobbles on various elevations of the sea-floor gives more evidence of submergence. Finally, the borings into four coral atolls have all shown that shallow-water deposits extend for at least a thousand feet below sea-level in all cases; in fact, the submergence of atolls in general seems probable.

The explanation of the widespread submergence is not clear, but the possibility should be considered that it has been due to a change of sea-level rather than of the lands. An alternative which seems somewhat more likely is that diastrophic submergence has been proceeding over a long period of time, but that sea-level changes have also been significant in producing the present conditions.

Summary of Discussion

Dr. Atwood asked if there really had been any careful research into the quantity of water required to produce the ice of the Pleistocene glaciation. Dr. Shepard did not think so, but felt that some geologists rather underestimated the thickness of the ice. In view of the evidence of Tertiary submergence, he was of the opinion that it played the chief part in the formation of the canyons rather than lowering of sea level due to glaciation.

Dr. Atwood stated that in his judgment these submarine canyons represent a short period of time and were formed by extremely quick action of running water at some period of emergence, and felt that the amount of water held as ice should be considered.

Dr. Tully remarked that the steep walls and flat floors of the land canyons can be followed out to sea, and then asked if Dr. Shepard had investigated the canyon off the boundary of Canada and U.S.A., which was 2,000 fathoms at the inner limits and 2,000 to 3,000 fathoms at the outer limits.

Dr. Shepard considered the upper part of this canyon to be a glacial trough, but out beyond that it was a typical submarine canyon.

Dr. Tully asked how the steepness of the canyon walls could be maintained, and Dr. Shepard replied that all the troughs have extremely steep walls, and may be a result of the constant disintegration resulting from marine borings. The glacial valleys have steep walls, but all types of barred basins that the canyons have not. You would maintain then that these canyons are fundamentally of the river origin, said Dr. Tully, and in reply Dr. Shepard agreed, stating that they are at right angles to the coast, whereas fault-structures are parallel to the coast. Dr. Shepard then exhibited the depth-sounding records of the steamer express from Wellington to Lyttelton.

Dr. Cotton said that the submarine canyons were quite obvious features of submergence, but could not local movements of land produce the submergence? On the New Zealand Marlborough coast enormous block-faults are a prominent feature, and there may be block faulting under the sea off the coast. He felt he could not trust subjective contouring of the large canyons as much as that of the smaller canyons.

Dr. Shepard agreed that the subjective drawing of the contours by Veatch and Smith must be treated with reserve.

Mr. Fyfe remarked that several years ago the Union Steamship Co. carried out extensive traverses taking depth soundings from Cape Campbell to Akaroa. The contours indicated that the canyons in this area mentioned by Dr. Shepard were basin-shaped and parallel to the coast, and he agreed with Dr. Cotton that they were probably structural. Dr. Cotton added that if such canyons are found off the Dunedin coast he would not question them because the geology at Dunedin is different from that at Kaikoura.

Mr. Healy asked if these might not have been warping apparently round the margin of the Pacific which is an active belt, but, on the other hand, Dr. Shepard had illustrated similar canyons in the stable areas of the Atlantic. Did the longitudinal profile show warping or not?

Dr. Shepard replied that under-water canyons are just as large on the Atlantic coast as they are on the Pacific, and that the longitudinal profiles did not show any warping. He was inclined to agree with Dr. Atwood in stating that they were cut very rapidly.

In reply to Dr. Westerveld's query—Do these canyons go to different depths or are they fairly constant?—Dr. Shepard said, "That is our weakest point and will be the subject of further investigation with the improved apparatus that is now being installed." He could not say definitely that they all ended at a certain more or less constant depth.

NOTE ON DROWNED ISLANDS IN THE PACIFIC

By Richard A. Sonder, Zürich, Switzerland

It seems of interest in the framework of this symposium to call attention to a curious level problem connected with the flat-topped seamounts existing in great number in the Pacific. As I have presented a more extensive paper to the eighteenth International Geological Congress in London, only a short exposition will be given hereafter.

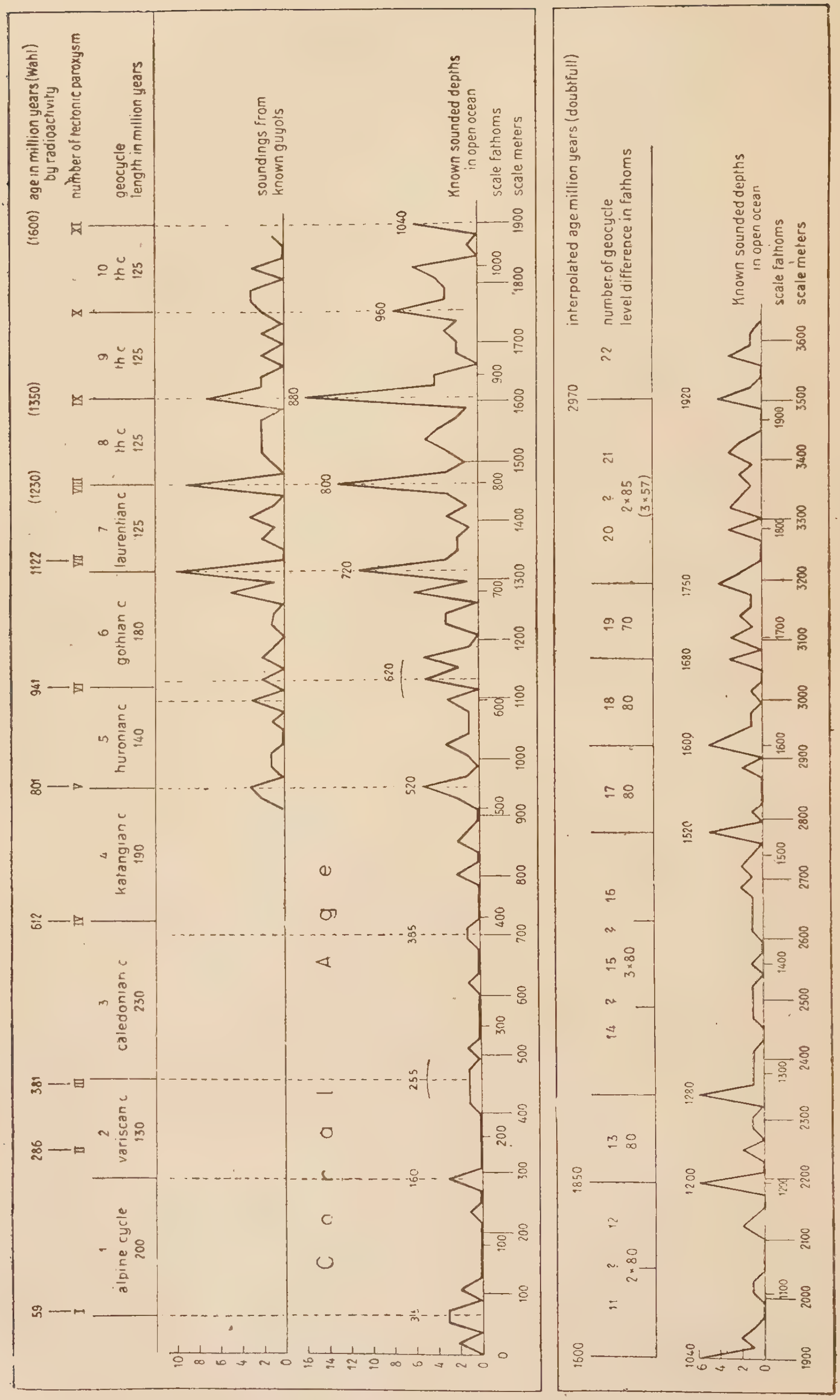
Plotting the number of known seamounts by classifying them according to the depth in fathoms of the top (from 500 to 1,000 fathoms) in a graphic representation (see figure) it becomes obvious that certain levels are clearly preferred. The result is practically the same if we use only the data given by Hess (1946) or the general sounding list of the Hydrographic Office at Washington (the two lower curves) for the Pacific north of the Equator (Pilot Chart 2603). The visible maxima seem to be more or less evenly spaced (about 80 fathoms) especially towards depth.

If the seamounts are drowned islands and are the older the deeper below the actual surface they are, we can hardly escape the conclusion that all islands in the open oceans are subjected to a slow secular drowning. One probable cause of this slow drowning may be the secular sedimentation in the open ocean, as Hess has suggested. If for rather obvious reasons the sedimentation rate on the flat-topped submarine cones is less than on the surrounding ocean bottom, then a slow sedimentary burying of these cones must take place with the ages, calling for a slow drowning of the tops due to isostatic adjustment. Recent probing of bottom sediments, made on a flat-topped seamount in the Atlantic, north-east of the Bermudas seems to confirm this explanation. The top plateau stands at 841 fathoms and the sounding core of the sediments showed Eocone chalk below 8 in. of globigerina ooze (Ewing, 1948). On the surrounding deeper ocean bottom the sedimentation is far more intense, and only far younger sediments can be found there in the cores. There may be other causes for the secular drowning such as a tectonic deepening of the oceans with time, an increase of the total water content. I have dealt with these possibilities in other papers (1942, 1948).

Assuming that these flat-topped seamounts are old volcanoes which preferentially rose at times of pitched tectonic diastrophism within the earth's crust, one is tempted to parallelize the preferred levels of the graph with the times of pitched tectonic volcanic activity, clearly visible in statistics of radioactive age determinations of minerals (Holmes, Wahl). Such an attempt has been made in the graph. If this interpretation should be correct, then the secular drowning rate of the seamounts would be about 110 m. in a hundred million years.

How does such an estimate match with known borings on coral islands, which may be seamounts with an age younger than the first appearance of corals in the seas? To the International Geological Congress some new data have been presented in this respect. According to Wells and others (1948), borings down to about 760 m. (2,556 ft.) on Bikini were still in the Lower Tertiary. Also on the other atolls, where borings are known—for instance, Funafuti—the results were similar. Notwithstanding that these results suggest at first sight a far higher sinking rate of these islands than the present estimate, it is not certain that this must be so.

The borings made up to date are marginal borings and do not give the conditions at the centre of the atoll, where we have to expect probably the original volcanic cone. Coral islands do not only grow upwards, but also sidewards. Coral material broken loose by wave action may roll down the submarine slopes, with the result that in marginal borings beds of certain age are found at far lower levels than in more central borings. As we have to consider also the possibility of special tectonic level displacements which may have affected certain islands or of especially strong displacements of sea-level during the more recent history of the


age in million years (Wahl) by radioactivity
number of tectonic paroxysm
geocycle length in million years
59 I
286 II
381 III
612 IV
801 V
941 VI
1122 VII
(1230) VIII
(1350) IX
X
(1600) XI
1 alpine cycle 200
2 variscan c 130
3 caledonian c 230
4 katangian c 190
5 huronian c 140
6 gothian c 180
7 laurentian c 125
8 th c 125
9 th c 125
10 th c 125
soundings from known guyots
Coral Age
35
160
255
385
520
620
720
800
880
960
1040
Known sounded depths in open ocean
scale fathoms
scale meters
0 100 200 300 400 500 600 700 800 900 1000
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900
interpolated age million years (doubtfull)
1600
1850
2970
number of geocycle level difference in fathoms
11 ? 2×80
12
13 80
14 ?
15 3×80
? 16
17 80
18 80
19 70
20 ? 2×85 (3×57)
21
22
1040
1200
1280
1520
1600
1680
1750
1920
Known sounded depths in open ocean
scale fathoms
scale meters
1100 1200 1300 1400 1500 1600 1700 1800 1900
1900 2000 2100 2200 2300 2400 2500 2600 2700 2800 2900 3000 3100 3200 3300 3400 3500 3600

earth, it is obvious that the whole problem needs still far more data in order to find a reliable explanation of the origin of the seamounts and their age. In the meantime the interpretation of the chart could at least suggest that these drowned islands show some features which go back to the oldest history of our globe which we might still be able to decipher in form of geologic time-marks.

REFERENCES

HESS, H. H.: Drowned Ancient Islands of the Pacific Basin. *Amer. Journ. Sci.*, 244, 1946, pp. 772–791.

SONDER, R. A.: Shear Patterns of the Earth's Crust, &c. *Transact. Amer. Geoph. Union*, 28, 1947, p. 939.

——— Drowned Islands and the Origin of the Oceans. *18th Int. Geol. Congress*, London, 1948.

WELLS, J. W., and others: Drilling on Bikini Atoll. *18th Int. Geol. Congress*, London, 1948.

SOME PACIFIC AND ANTARCTIC SEA-FLOOR FEATURES DISCOVERED DURING THE U.S. NAVY ANTARCTIC EXPEDITION, 1946–1947

By ROBERT S. DIETZ, U.S. Navy Electronics Laboratory, San Diego 52, California

[*Abstract*]

During the U.S. Navy Antarctic Expedition, 1946–1947 (Operation HIGHJUMP), the recording echo sounder of the U.S.S. "Henderson" indicated the presence of a number of previously undiscovered sea-floor features. Several large, isolated, non-flat-topped seamounts were found, the shoalest of which rises to a depth of 540 fathoms. A volcanic origin is presumed for most of these seamounts as they are symmetrical in form and have slightly concave flanks varying in slope from 10 to 21°.

A spectacular, asymmetrical, fault-block escarpment with a foredeep was discovered north of the Easter Island Swell. This two-mile-high ridge has a slope of 11° on one side and a calculated slope of at least 63° on the other. Thus, this feature is more precipitous than any subaerial fault-scarp of comparable magnitude on the face of the earth. Another large escarpment was discovered extending out from Antarctica.

Profiles of the continental slope of Antarctica south of the Indian Ocean show it to be smooth and gentle, suggesting extensive deposition. No submarine canyons were definitely identified. The break-in slope between the shelf and slope occurs at depths from 230 to 280 fathoms. This is much deeper than the usual break-in slope which occurs at about 75 fathoms in most other parts of the world. It may be due to deep erosion by icebergs and glaciers, but certain other considerations suggest that it may result from the isostatic depression of Antarctica because of ice loading.

Most of the Pacific traversed appeared to have irregular topography, but the basins around Antarctica are smooth and comparatively featureless.

I. INTRODUCTION

During operation HIGHJUMP the U.S.S. "Henderson" (DD–785), under the command of Commander C. F. Bailey, made continuous soundings along her track with a model NMC-2 (RCA) echo sounder using 17 kilocycle sound pulses. Soundings of less than 2,000 fathoms were recorded automatically on a tape, and soundings of greater depths were obtained by the eye-ear method every hour. Because almost all of the ocean bottom traversed is deeper than 2,000 fathoms, a continuous automatically recorded profile was obtained of only a few topograpically positive features such as the tops of seamounts or escarpments. In this report a few features displayed on the " Henderson " fathogram are reproduced and discussed because they are of special geological interest.

II. SEAMOUNTS

A number of new seamounts were discovered during the San Diego to Antarctic passage. Four were found in the abyssal ocean off Baja California ; an especially large seamount was discovered in the south-west Pacific off New Zealand.

Figure 1A shows two symmetrical seamounts that were located about 300 miles south-west of Allaire Bank, off Baja California. The larger seamount rises to a sharp peak at about 860 fathoms and the smaller rises to a peak at 1,400 fathoms. The sides of these seamounts are fairly steep, having a maximum average slope angle of 19°(¹). Extension of the bottom echo when crossing the peaks indicates steep slopes parallel to the ship's track and suggests that the vessel " side-swiped " the seamounts rather than passing directly over their highest peaks.

Another seamount (Fig. 1B) was discovered off Baja, California, about 130 miles north-west of Allaire Bank, rising 1,400 fathoms from the abyssal sea-floor to a peak at 900 fathoms. The north side is irregular and concave and has a slope of 12° ; the south side is straight and featureless and has a slope of 16°. The summit is pinnacled and shows no evidence of terracing or truncation.

The seamount shown in Fig. 1C rises to a sharp peak at 540 fathoms. This symmetrical feature was discovered 220 miles west of Alijos Rocks, off Baja, California. Its slightly irregular and upwardly concave sides have an average slope angle of about 12°. The terrace which is present on the north slope at about 800 fathoms may be the result of wave erosion, but such a wave-cut origin is very questionable because echo extension suggests that this terrace is of rather limited horizontal extent normal to the recorded profile.

Another seamount (Fig. 1D) was crossed near Hiva Oa, in the Marquesas Islands, the presence of which is suggested by soundings on published charts. The flanks of this feature have a slightly concave form. The steeper northern side has an average declivity of 13°, with a maximum slope of 21° near the summit. The somewhat gentler south flank is marked by a series of pinnacles. A deep and irregular plateau extends to the north-east of the seamount. Some of the atolls of the Marquesas Group presumably rise from this plateau.

(¹) In this report the apparent slope angles are corrected assuming a 30° effective half-angle of the sound-beam. In other words, the sound-beam is assumed to be semi-directional. However, the effective half-angle of the beam cannot be accurately determined since it varies with numerous factors such as gain setting, roll of the ship, depth, &c. This correction is significant only for slopes greater than 15°, and the true slope is always greater than the apparent slope. The apparent slope is obtained by correcting the fathometer tape-slope for vertical exaggeration.

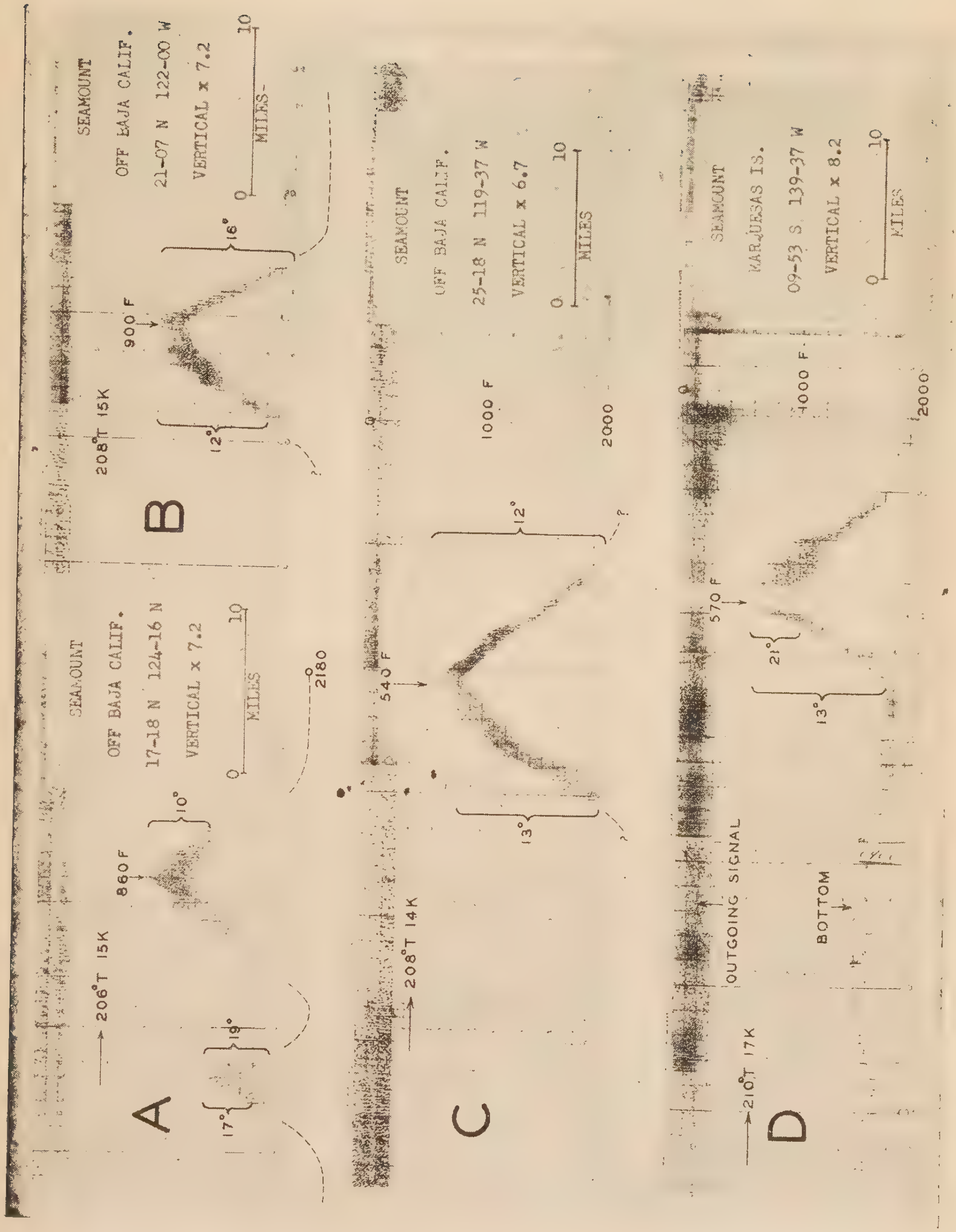


FIG. 1.—Echo sounder bottom trace (fathogram) of four Pacific seamounts

The largest seamount encountered on the cruise (Fig. 2A) is located in the south-west Pacific about 1,000 miles west of New Zealand in a sparsely-sounded region. This feature rises from a sea-floor depth of 2,700 fathoms to a minimum depth of 600 fathoms. The summit area is extensive but irregular, so that there is no evidence of wave truncation. The north slope has a declevity of 14°, compared with 21° for the south slope. Both slopes are slightly concave.

All of these seamounts have an appearance which suggests that they are volcanoes which are probably extinct. Such an origin is suggested by the simplicity and symmetry of form, the slightly concave slopes, and the average angle of slope which is always in excess of 10°, but never exceeds 21°. In addition, the seamounts off Baja, California, are located at no great distance from the volcanic Guadalupe Island and in a region of known volcanicity. Yet there is a slight possibility that the seamount shown in Fig. 1B is a south-facing fault escarpment rather than a volcanic mass. The slight asymmetry of the feature and the straightness of the south slope suggests this alternate interpretation. However, although it is difficult in most cases to conceive of any other origin, the volcanic explanation for these seamounts must remain tentative because it is postulated purely on a geomorphic basis. Such criteria for determining the nature of sea-floor features are not well established, particularly when only sounding profiles are available.

None of the seamount profiles show any good evidence of terracing or summit truncation such as would result from wave cutting if the seamounts had stood above or near sea-level during a part of this history. This is in contrast with the discovery by Hess(1) that most seamounts in the west central Pacific that rise to depths shoaler than 1,000 fathoms show summit truncation. If the ocean floor has been relatively stable so that summit truncation is to be explained by a former lower stand of sea level, then these seamounts must be younger than those in the region described by Hess.

During the Pacific passage the writer was impressed by the paucity of large seamounts. Vast stretches of the ocean showed no sounding less than 2,000 fathoms. Most of the seamounts discovered are located off Mexico at no great distance from the continent. Existing charts indicate numerous seamounts in this region which show that it has had a volcanic or diastrophically active history. Although large seamounts are rare on these fathograms of the deep Pacific from south of the Mexican area to the Antarctic Ocean, except in the Marquesas Islands region, the eye-ear soundings show that the oceanic floor is rarely smooth, but is, rather, generally rugged and irregular.

III. EASTER ISLAND SWELL

A profile across the northermost portion of the Easter Island Swell is reproduced in Fig. 2B. Existing charts such as H.O. 2562 show that this swell has a linear extent of several thousands of miles between Easter Island and the Antarctic. This swell is apparently a system of submarine mountain ranges comparable to some of the large cordilleras on the continents, and it must be the combined result of folding, faulting, and volcanism. Soundings obtained by the eye-ear method prior to passing over the swell revealed a flat bottom, with no indication of a foredeep. The profile across the swell shows a general absence of concave

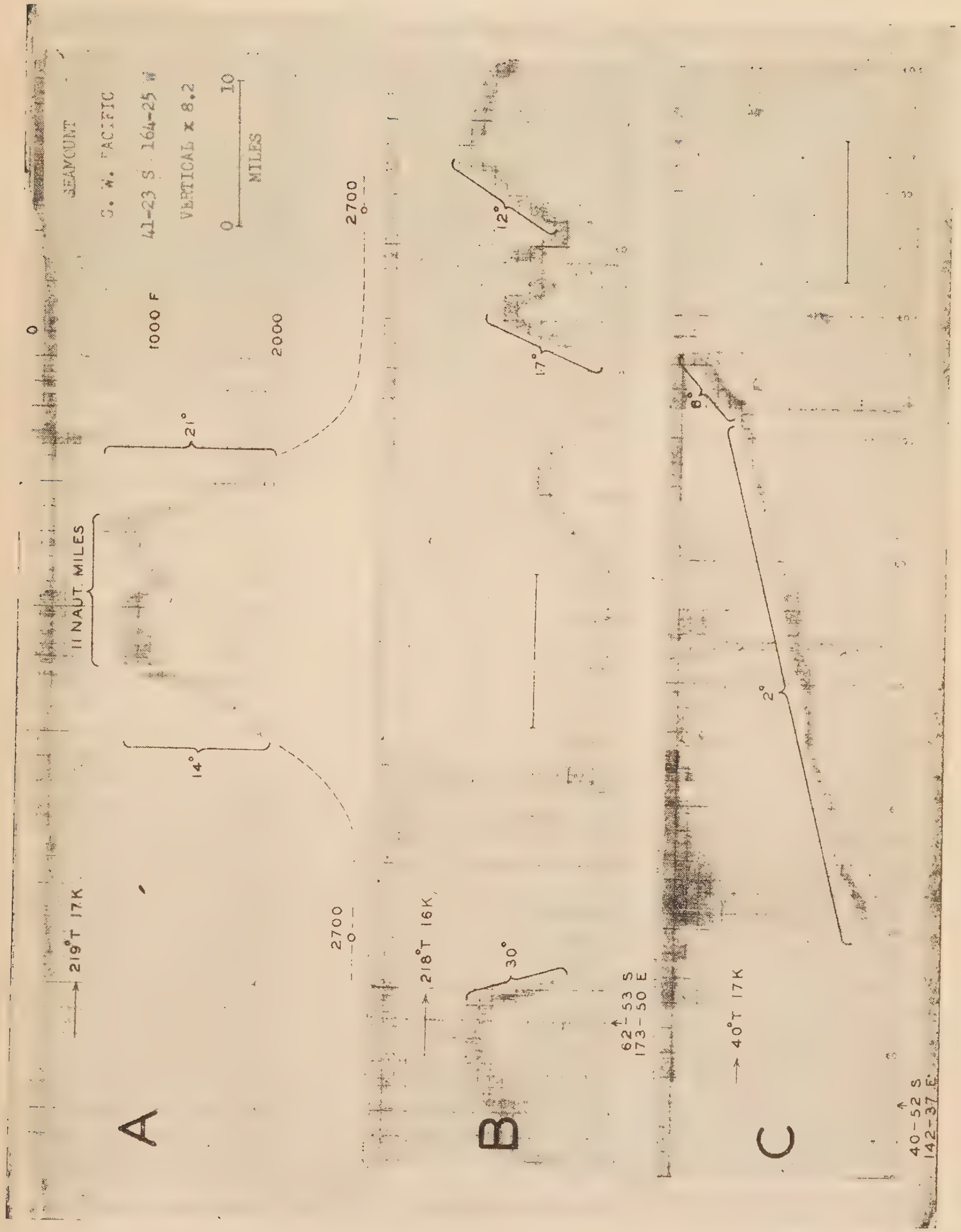


FIG. 2.—Fathograms showing a south-west Pacific seamount, the Easter Island Swell, and the continental slope of South Australia

slopes. The presence of straight and slightly convex slopes suggests faulting and folding. The 30° southern flank of the northernmost mountain is so steep that it is probably a fault-scarp. Here again there is no good evidence of summit truncation by wave erosion.

IV. ESCARPMENTS

A remarkable escarpment (Fig. 3A) was discovered in the Antarctic Ocean about 80 miles north of the Easter Island Swell, to which it may be genetically related. This feature, which has the appearance of a north-facing, tilted fault-block, rises from a depth of about 3,000 fathoms to a sharp peak at 1,180 fathoms, making a total relief of about 2 miles. Eye-ear soundings obtained prior to crossing the escarpment reveal a foredeep at its base. The fault-face has a straight profile and a declivity of 63°, which is a minimum because, in calculating the slope, it was assumed that the ship traversed the escarpment at right angles. The gentler south slope is straight and has a slope angle of 11°. The steepness of the escarpment, the asymmetry of the feature, and the presence of a foredeep clearly indicate that this feature was produced by high-angle faulting of large magnitude. The absence of effective erosive processes deep beneath the ocean has permitted the preservation of this fault block with " text-book-like " simplicity. The precipitousness of the escarpment probably exceeds that of any continental escarpment of comparable relief. For example, the angle of slope of the eroded east face of the Sierra Nevada fault-block averages about 18°.

A second escarpment of considerable magnitude was located during two crossings of a submarine " spur " 300 miles in length extending out from the Antarctic Continent adjacent to Princess Ragnhild Coast. Figure 3B shows a profile of this escarpment obtained during the west-to-east crossing. This profile indicates the probable faulted nature of the eastward side of the " spur." The escarpment drops with a 44° declivity from 1,100 fathoms to at least 2,700 fathoms, and eye-ear soundings suggest the presence of a foredeep. This escarpment is possibly the result of high-angle faulting or, more likely, by horizontal movement along a fault which has displaced a portion of the Antarctic Continent and formed the submarine " spur." This feature reminds one of the Gordo escarpment off northern California, which, according to Shepard and Emery(2), may have been formed by horizontal displacement of the continental shelf along an extension of the San Andreas fault.

V. CONTINENTAL SLOPES

During her passage around the Indian Ocean sector of the Antarctic Continent the " Henderson " remained, for the most part, in the deep water of the basins surrounding the continent. These basins are extremely level suggesting a thick fill of sediments. No seamounts were found. At times the vessel ran along the continental slope at depths shoal enough to be recorded on the echo-sounder tape. Irregular fathograms were obtained, but the presence of submarine canyons or other indentations into the continental slope cannot be definitely determined because of constant manœuvring around the ice. There is no detailed record of the changes in course during this manœuvring so that many traces which appear to show indentation in the slope may have been produced by changes in course along a smooth slope.

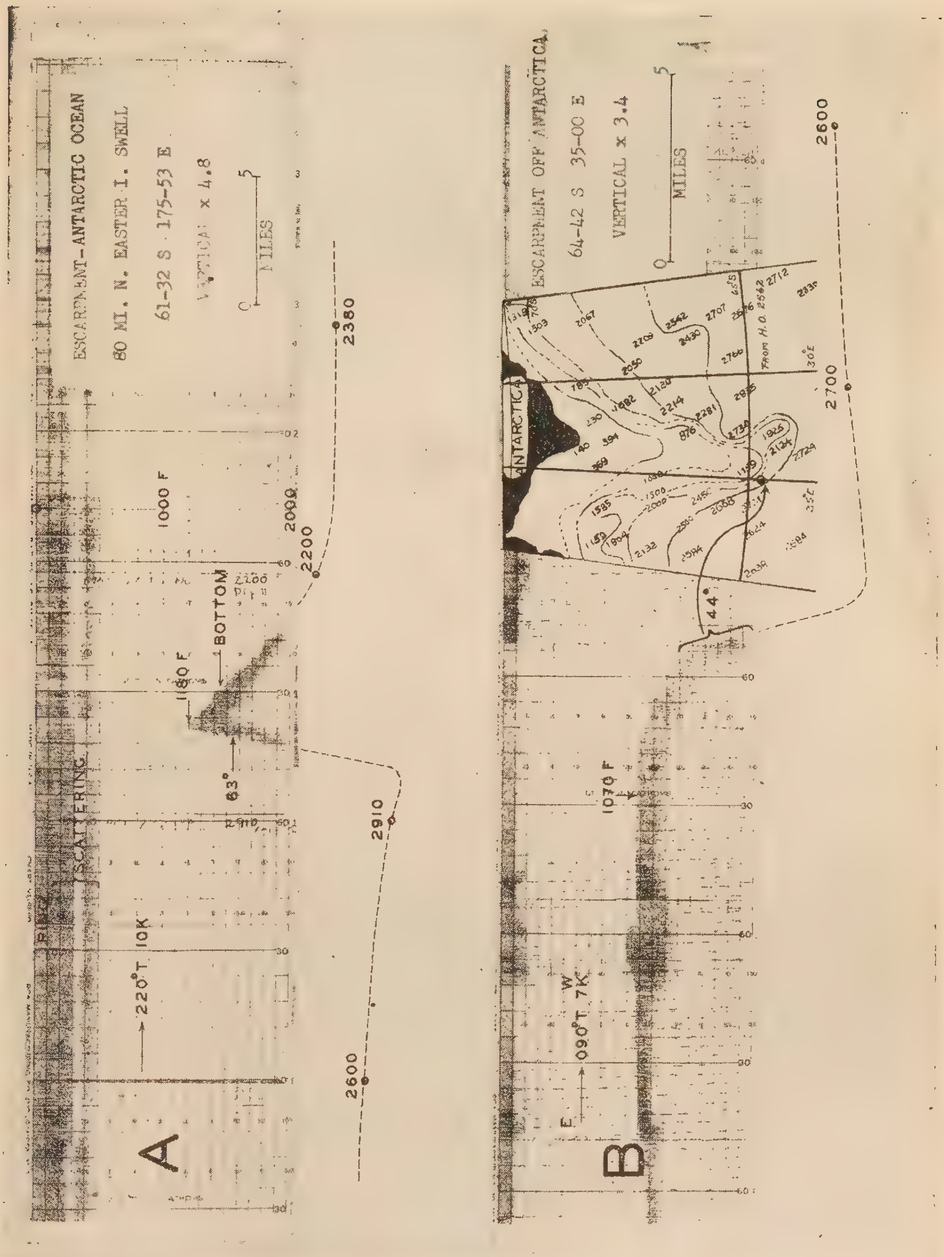


FIG. 3.—Fathograms of two Antarctic sea-floor escarpments

The " Henderson " reached the continental shelf of Antarctica only once. On this occasion an excellent profile almost directly up the continental slope was recorded from the Indian Ocean to the Mackenzie Sea (Fig. 4). In comparison with the slopes around other continents of the world this profile shows a slope that is remarkably long, smooth, and gentle. It has a long, sweeping, concave form, and it varies in declivity from 2° near the top to about one-fourth of 1° at the bottom. There the slope fades into the abyssal sea-floor, 150 miles out from the continental shelf. The smoothness, gentleness, and concavity of the slope give it the appearance of foreset deltaic beds. However, the writer favours the theory of Shepard(3) and others of the structural origin of continental slopes in preference to a sedimentational origin. It is likely that the present form of the slope is the result of extensive sedimentation of detritus carried across the shelf and deposited unconformably along an originally steeper slope. According to this interpretation, this slope can be considered to have reached a physiographic " old age."

The top of the slope is marked by a sharp break at 280 fathoms, shoreward of which is a deep but level continental shelf. This deep break in slope is in marked contrast to the shelves in non-polar regions which generally have their break at about 65 fathoms. The ship traversed about 80 miles of level and featureless shelf before passing again over a sharp break at 280 fathoms. An oblique traverse down the slope to the south-west showed a continental slope similar to that of Fig. 4 and indicated the absence of submarine canyons cut into the slope in this region.

An examination of the depth profiles obtained during five other traverses across the break-in slope of the continental terrace obtained by the U.S.S. " Currituck " on the west Pacific and Indian Ocean side of Antarctica showed breaks at from 230 to 280 fathoms. Thus this excessive depth of the break-in slope appears to have wide geographic distribution. This may result from deep erosion by glacial ice tongues or by large grounded icebergs. However, the flat nature of the shelf noted in the Mackenzie Sea with a complete lack of irregularities belies ice erosion at least in this area. Hence it is possible that the depth of the Antarctic shelf is explained by isostatic depression of the Antarctic Continent as a unit because of ice loading.

A second continental slope profile was obtained when the " Henderson" ran up the continental slope of South Australia from the South Australian Basin into Bass Strait between Australia and Tasmania (Fig. 2c). This slope is irregular and hummocky, with an abrupt change in slope at 550 fathoms. The lower portion of the slope has a declivity of about 2° ; the top portion has a declivity of 6°. The break in slope between the continental slope and the shelf occurs at about 80 fathoms. Judging from published charts, this slope is of normal declivity and form. However, the change in slope at 550 fathoms is striking and is no doubt significant. One possible explanation for this might be that detritus transported across the shelf also moved down the steep 6° slope and has built up a wedge of sediment at a gentler angle of repose of 2°. The hummocky form of this deeper slope might be the result of landslides or of other mass movements.

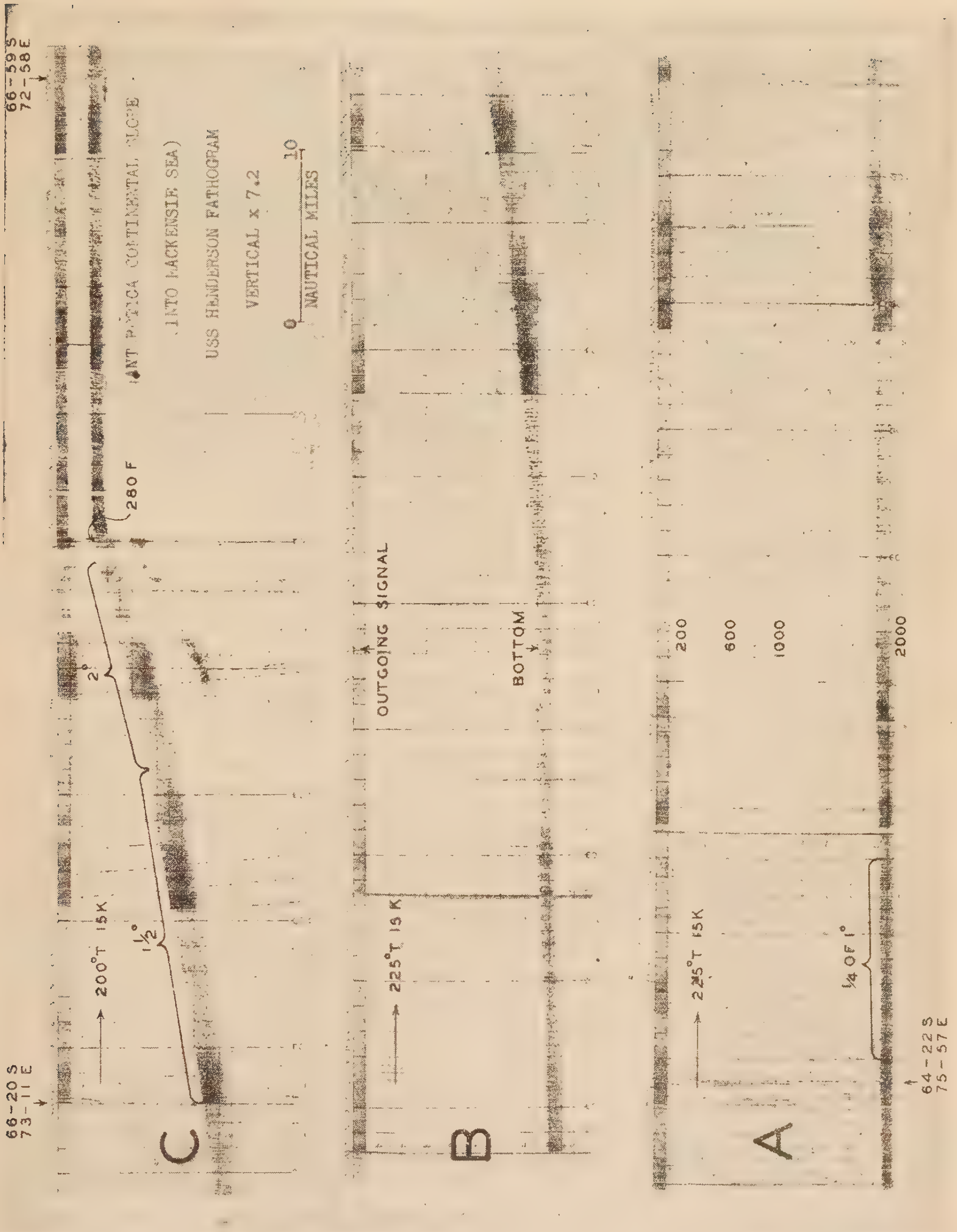


FIG. 4.—Fathogram of the continental slope of Antarctica near the Mackenzie Sea

VI. CONCLUSIONS

The development of the continuously recording echo sounder makes possible much more detailed studies of sea-floor geomorphology than was possible in the past. However, echo-sounder records still have many limitations such as generalizing the bottom because of the poor directivity of sound so that fathograms must be interpreted with caution. It is also unfortunate that standard echo sounders have a tape recording limit of 2,000 fathoms as nearly all of the ocean floor is located at depths in excess of this.

In studying sea-floor features from fathograms one is generally assisted by a simplicity of form resulting from the absence of competent erosion processes like those which add greatly to the complexity of subaerial features. It follows from the lack of erosion that some sea-floor features are extremely old, perhaps as old as the ocean basins themselves. Such physiographic "museum pieces" are in contrast to subaerial geomorphic features which are generally considered to be entirely late Tertiary or younger.

REFERENCES

(1) HESS, H. H. (1946): Drowned Ancient Islands of the Pacific Basin. *Am. Jour. Sci.*, Vol. 244, pp. 772–791.

(2) SHEPARD, F. P., and EMERY, K. O. (1941): Submarine Topography off the California Coast. *Geol. Soc. Am. Special Papers* No. 31, pp. 35–41.

(3) ——— (1948): *Submarine Geology*. Harper and Bros., New York, pp. 193–194.

THE GEOLOGY OF BIKINI, MARSHALL ISLANDS

By H. S. LADD and J. I. TRACEY, U.S. Geological Survey

(Read by Dr. K. O. Emery)

[*Abstract*]

Soundings have been carried out on the sloping shelf around Bikini, and the slope indicated was relatively steep. A seamount was also indicated lying to the north-west. The projections of the reef are reflected in projections at depth. Soundings around the Rongelap Atoll also indicated steep shelves and an associated seamount at Eniwetok Atoll. A deep terrace at 750 fathoms lay to the north-west and a similar one to the south-east. North of Bikini is a shallow seamount which was illustrated in some detail. Deep-sea sediment distribution was illustrated on plan. Deeper sediments are red clay, but at 2,300 fathoms to 2,000 fathoms it is replaced by globergina ooze, and between this zone and the atolls there is a variety of sedimentary types. Sonic soundings around Bikini indicate a slope of a maximum of 45°, and close soundings were carried out adjacent to the atoll with leadline. Cross-sections of atolls and seamounts were illustrated. The former indicated steeper slopes at the atoll, but the latter had a somewhat different profile which was comparable up to 600 to 700 fathoms, and above that a decrease in slope or a rounding off. Sounding within the lagoon itself indicated a terrace around the perimeter, widest at the outward projections and narrowest at the inward projections. The subsidence theory may hold ground for atolls built up from the seamounts, but this would require a deep drill-hole to prove. At Bikini there had been planing at lower sea-levels during glaciations. Growth of the rate of coral is estimated at 1 mm. per year from the reef surface. There was a marked concentric distribution of sediments within the lagoon itself.

Professor Yonge stated his experience on the Barrier Reefs off Queensland, where the coral grew in confused masses, and, under heavy seas, it was broken up and piled up on the reef, and on other parts of the Barrier the reverse took place, and broken material formed submarine talus slopes. In answer to a question concerning light-penetration, Dr. Emery stated that some measurements had been taken, and that light seemed to be effective 150 to 180 ft. in the lagoon, and apparently this was the same outside the reef.

Dr. P. Marshall remarked that the distribution of organisms and sediments described was very similar to that observed at the Cook Islands.

MULTIPLE STANDS OF THE SEA IN POST-GLACIAL TIMES

By RHODES W. FAIRBRIDGE, University of Western Australia

IN his memorable work on the most recent eustatic drop in the level of the sea Daly (1920) reckoned on something of the order of 20 ft. and collected from the world-wide literature, willy-nilly, it might seem, all references he could find to " fairly recent " raised beaches, terraces, and the like.

More than adequate evidence is now available to indicate that quite a number of Daly's levels really belonged to a late Pleistocene date (possibly Zeuner's " late Monastir " level, approximately 25 ft. in the type area of the Mediterranean) and identified far and wide in the Pacific (see Stearns, 1941, &c.) and other oceans. On the other hand, the various lower figures obtained by many workers have rashly been discredited altogether by the late Professor Douglas Johnson (1933), who decided that all marine erosion surfaces below " hurricane-beach " height were the products of the present cycle of erosion.

The wide experience of and many papers by Stearns (1941, 1945, &c.) should be sufficient demonstration that in fact some of these lower levels are truly eustatic. Stearns and others attribute them to a mid-Recent stand of the sea at 5 ft. above the present.

In certain particularly favoured areas, however, it has been possible to recognize not one, but *four distinct stands of the sea* in post-Glacial times. Kuenen (1933) found these in the East Indies and placed them at 4–5 m., 1½–2 m., and ½–1 m. above the present sea-level, which constitutes the fourth and latest stand. Working independently, the author and C. Teichert have lately found very similar traces in Western Australia (10–11 ft., 5–6 ft., 2–3 ft., and the present zero-level bench). These were first recognized in the Abrolhos Islands (Fairbridge, 1948) and on Rottnest Island (Teichert, 1948), and we have both followed out the evidence together up and down the very stable coast of Western Australia for nearly 1,000 miles. Further evidence from islands and mainlands bordering the Indian Ocean and elsewhere suggests that these indicate truly eustatic sea-levels. This was suggested already over a century ago by Ehrenberg (1834). Comparison with recent studies in Sweden suggest that they have all been completed during the last four thousand years. The highest sea-level appears to correspond with the " Atlantic " phase of climatic optimum (Flandrian stage of Dubois).

The fact that these terraces are horizontal in attitude and separated from one another by short vertical cliffs, with other evidence, has led to the conclusion that periods of stand-still were protracted, but that changes in level were carried out in a very short time (probably less than a century for a 5 ft. drop). The sea-level appears to have suffered short, sharp drops (Fairbridge, 1949) ; there seems to be little likelihood of any oscillating up and down below the present sea-level in these post-Glacial movements. Several factors may be combined to explain the remarkable development and, consequently, the discovery of these benches.

First, there is a very small tidal range on much of our Western Australian coast-line, and likewise in the East Indies and elsewhere in the Indian Ocean. A neap rise and fall of less than 12 in. is normal at Fremantle. This means that at any rate the terraces at 5–6 ft. and 10–11 ft. above datum (low-water springs, which is the level of the contemporary bench) are generally clear of actual marine erosion and are only being slowly attacked by spray and rain. Shells in the associated raised beaches often still maintain much of their original colour.

Secondly, off-shore reefs and wide fringing reefs protect much of our coast-line from storms. Hurricanes are not experienced. The benches are, of course, found best preserved in protected bays, inlets, and lagoons. Thus, in the Abrolhos Islands, the broad lagoon is flanked by low cliffs, in which here and there may be found all four levels rising in steps. On Rottnest a series of inlets, which were open to the sea until a few centuries ago, have now been sealed off by advancing sand-dunes to form a series of salt-lakes. The cliffed margins of these lakes now exhibit the most beautiful series of undercut notches, benches, and raised shell-beds which it has ever been my good fortune to see. Such perfect preservation is, of course, not found everywhere ; it would hardly be reasonable to expect to find a 2–3 ft. terrace preserved from the present attack of the sea in any but exceptional places. Normally this low terrace is completely destroyed or reduced to a sloping ramp which leads up into the 5 ft. notch. In exposed spots the contemporary 2 ft. and 5 ft. notches are all smoothly graded into one and only the 10 ft. bench stands out like a visor above the contemporary terrace.

The third factor of importance in making these West Australian benches so striking is the fact that they are all cut in limestone. In places it is a coral limestone, or a massive lagoon limestone, but generally it is a sandy calcareous eolianite. All are of Pleistocene age, but generally extremely indurated and hard. The nature of limestone, as I have tried to indicate already (Fairbridge, 1948, 1949), is particularly favourable to the formation of a very massive, yet clean-cut, marine platform at *exactly* the height of low-water springs. This level is the critical lowest limit of subaerial erosion and also is close to lowest limit of super-aerated surf. The latter is rendered temporarily acid in its reactions to limestone under certain bio-chemical and physico-chemical conditions (extemely variable temperatures, CO_2 and pH ranges). With the sharp changes experienced in this zone limestone is alternatively dissolved (tending to reduce the level of the land to a horizontal plane coinciding with low-water springs), and alternately precipitated (producing a travertine filling in all the interstices of the limestone and rendering the rock so massive and hard that it rings to a hammer blow and was even used by primitive man for " flint " artifacts). The result is a horizontal bench of extreme resistance. It is realized that purely biological and mechanical factors are also highly active in this same inter-tidal zone, but are not considered to be of the same significance as chemical erosion. Research into these various operations is still proceeding.

The scientific consequences and implications of these discoveries may be of considerable interest to geomorphologists and archæologists. If the levels themselves are truly eustatic—*i.e.*, world-wide—and if the four changes in level have actually taken place along the coasts near settlements of classical antiquity, such as Egypt and Mesopotamia, then important correlations may be worked out. An interesting essay in this direction was made by H. W. Pearson already in 1901, but this and other early attempts are full of weaknesses due to uncritical reading of evidence, to a failure to recognize the full complexity of the problem, and so on.

Finally, looking to the widespread coral islands of the Pacific, it would be surprising indeed if further intensive study here also did not reveal traces of these most recent strand displacements.

BIBLIOGRAPHY

EHRENBERG, C. G. (1834) : " Ueber die Natur und Bildung der Corallenbanke des rothen Meeres. *Phys. Abhandl. k. preuss. Akad. Wiss.* (Berlin), for 1832, pp. 381–438.

FAIRBRIDGE, R. W. (1948) : Notes on the Geomorphology of the Pelsart Group of the Houtman's Abrolhos Islands. *Journ. Roy. Soc. West. Aust.*, Vol. 33 (for 1946–47), pp. 1–43.

——— (1949) : The Geology and Geomorphology of Point Peron, Western Australia, *Journ. Roy. Soc. West. Aust.*, Vol. 34 (for 1947–48), No. 3. (In the press.)

JOHNSON, D. W. (1933) : Supposed Two-meter Eustatic Bench of the Pacific Shores. *C.R. Congr. Int. Geogr.* (Paris), Vol. 2, pp. 158–163.

KUENEN, P. H. (1933) : Geology of Coral Reefs. *The Snellius Expedition*, Vol. V, Geological Results, Pt. 2, 125 pp.

PEARSON, H. W. (1901) : Oscillations in the Sea-level. *Geol. Mag.*, Dec. IV, Vol. 8, pp. 167–174, pp. 223–231, and pp. 253–265.

STEARNS, H. T. (1941) : Shore Benches on North Pacific Islands. *Bull. Geol. Soc. Amer.*, Vol. 52, pp. 773–780.

TEICHERT, C. (1948) : Late Quarternary Sea-level Changes at Rottnest Island, Western Australia. *Proc. Roy. Soc. Vic.*, Vol. 59 (2), pp. 63–79.

MARINE EROSION

By RHODES W. FAIRBRIDGE, University of Western Australia

OBSERVATIONS on the nature of marine erosion, resulting in the formation of contemporary marine benches, platforms, terraces, or reefs around the shores of the Pacific, Indian, and Atlantic Oceans have puzzled the writer for some time. Investigations into the relative effects of chemical, biological, and mechanical erosion here have led to conclusions which concern the whole nature of marine erosion, ranging from the emergent " wave-cut " terraces, which fringe so many Pacific islands, to the broad floor of the continental shelf.

THE " NORMAL " SHORE PROFILE

Reading that the normal shore terrace was theoretically part of a profile of equilibrium achieved by mechanical erosion operating to wave-base (according to the Gulliver, Fenneman, Davis, Johnson school), it is somewhat astonishing to find in reality that the *most usual* profile of the continental margin *in the more stable parts* of the earth is in fact a series of steps, either sloping gently outwards or often even more or less horizontal (see the many recent papers on continental shelves and submarine terraces). These observations have been based mainly on a study of the more recent hydrographic charts (many of which are based on very accurate sonic sounding). Notice that emphasis is placed on the phrases " most usual " and " more stable," because the following remarks hardly apply either to entirely new shores, such as those of a freshly erupted volcanic island, or to the rapidly emerging shores of formerly glaciated areas which had been isostatically depressed, or again to highly mobile shores in the grip of active tectonic movement. In short, I am thinking of the normal coasts of the stable parts of the Continents of Australia, Africa, America, &c., but, nevertheless, the conclusions may also be seen to apply to many of the younger shores as well.

The general consensus of opinion now indicates that most continental shelves were, at least superficially, sculptured by shore-line erosion during the Pleistocene into series of platforms at various levels. The question of the degree to which glacial lowering of sea-level or tectonic oscillation of the continental border contributed this eventual result need not concern us for the present (*cf.* Lewis, 1937 ; Novak, 1938 ; Bourcart, 1938 ; Umbgrove, 1946 ; Fairbridge, 1946, 1947A, 1948). Thus, for example, the continental shelf off Western Australia appears to consist of a series of terraces at 3–5, 10–15, 25–30, 55–60, and at about 100 fathoms below sea-level. Other stable coasts exhibit very similar features.

We must conclude that no such thing as a mature offshore profile of equilibrium exists to-day, since major changes of sea-level, ranging through the Tertiary and Pleistocene, right up till to-day, have kept the profile in a continuous state of alternate rejuvenation and drowning.

It is apparent that the few thousand years, which have elapsed since the last major submergence of the continental shelf have not been a sufficient span of time to permit mechanical erosion at wave base to reduce the ruggedness of these submarine terraces to a smooth profile ; sedimentation may be helping to fill up some of the depressions and round off the contours, but the essential sharpness is still there. The power of waves and currents to sort and distribute loose sediment across the shelf is undoubted, but a serious question is raised as to the strength of waves and currents to rapidly erode hard rock outcrops at depths of, say, 10–100 fathoms.

HORIZONTAL PLATFORMS

My problems really started when I noticed that the average " wave-cut " platform of to-day is generally *steep-to* on the outside edge and is essentially horizontal on the surface. This means that the platform does *not* slope gently outwards to merge into the off-shore profile that descends to 100 fathoms or so, as we would have to believe from text-book figures (*e.g.*, Johnson, 1919–38, Fig. 37). A soft, sandy, or muddy coast may well be endowed with a gently sloping off-shore profile, but not a rocky coast ; in fact, I have the impression that the cliff foot on the average rocky coast is being eaten back more rapidly than is the outer margin of the platform (see, for example, Gill, 1949) ; the older the coast (*i.e.* the longer it remains stable in relation to the sea-level) the wider the platform will become. Such a conclusion is hardly in conformity with the " traditional " teachings of the Johnson school of marine erosion.

Such contemporary horizontal platforms may be seen *par excellence* in the Pacific and around the shores of Australia. These regions are endowed with widespread limestone coasts, which, because of their solubility in sea-water in the inter-tidal belt under certain highly specialized bio-chemical and physico-chemical conditions on the warmer reef-flats, are particularly favourable to the rapid erosion of these broad horizontal platforms. It makes no difference whether the limestone in question is of coral origin or is a massive chemical rock, or yet again is the sandy calcareous eolianite commonly found on more arid coast-lines.

In certain favoured places these contemporary platforms range up to half a mile in width ; in others perhaps only a few feet. Normally they are horizontal, though the outer part may be undercut and slope away ; or it may have an elevated rim. The inner part may be truncated sharply by cliffs ; or again it may rise in a gently sloping ramp, particularly so in exposed places where there is a considerable swash.

It should, however, be emphasized that horizontal reef platforms are also found in rocks other than limestones, such as shale, sandstone, schist, and so on, but massive rocks like granite and basalt are so resistant to subaerial and intertidal weathering that, in the limited time available since the last eustatic change of sea-level (possibly less than one thousand years), no appreciable benching has occurred in them. There are thus ideal bench-forming rock types, and others which are not at all favourable.

The explanation of this horizontal benching has been sought with considerable curiosity. Investigations are still in progress. But this much at any rate is clear : as Bartrum, in New Zealand, has already very satisfactorily demonstrated, subaerial erosion operates rapidly and deeply on many rock-types, but is arrested in depth by sea-level, for alkaline sea-water acts as a preservative for most rock materials, in contrast to the destructive character of acidic rain-water. Thus, below the inter-tidal belt, the erosive action of the sea is negligible in contrast to that of the atmosphere ; the critical zone of erosion is in the inter-tidal levels, where rock materials, loosened and partially disintegrated by subaerial forces, are etched, abraded, quarried, and washed away by the surf.

In this same critical surf zone certain curious temporary chemical changes take place. Although sea-water is normally alkaline, here the action of the surf *causes large amounts of* CO_2 *to be taken into solution,* thus lowering the pH and rendering the water and spray temporarily " acid " and thus corrosive. Drop in temperature in the water on the reef flat at night and, in the absence then of photosynthetic removal of CO_2 by plants, normal respiration of plants and animals in the inter-tidal area will all tend to the same end—that is, an increase in acidity. The relative importance of each factor is yet to be worked out.[1]

---

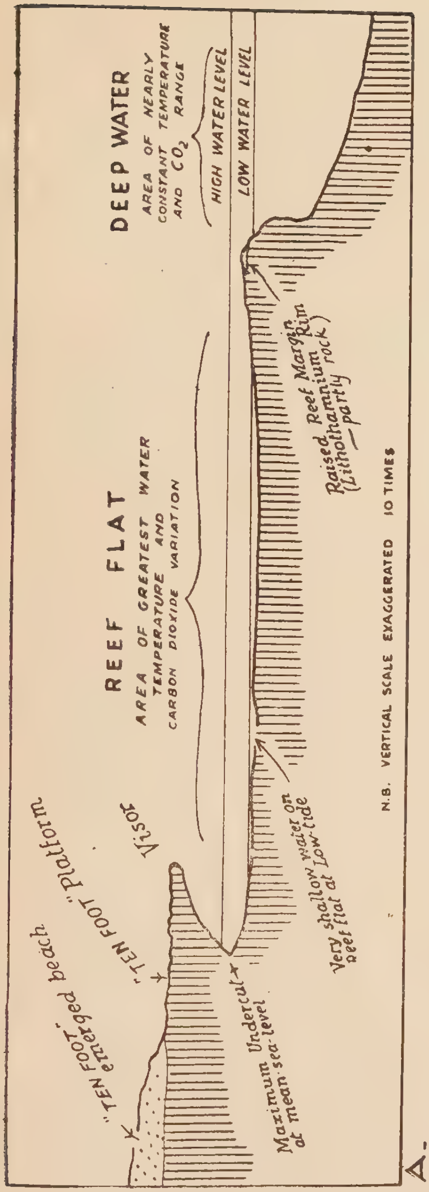
(1) I have recently come across a reference which helps to explain the unfavourable reaction of certain rocks to bench-forming processes. Half a century ago J. Joly, of Dublin, carried out careful experiments which demonstrated that aerated sea-water dissolved various silicate minerals and igneous rocks much faster than did fresh water similarly aerated. Hornblende is eight times ; orthoclase fourteen times ; obsidian four times ; and basalt three times more soluble in salt than fresh water. (Joly, J. (1901) : " Expériences sur la dénudation par dissolution dans l'eau douce et dans l'eau de mer." *C.R. Congr. Geol. Int.* (VIII, Paris, 1900), Vol. 2, pp. 774–784.) Naturally there is greatest aeration (acidity) of the sea-water in the intertidal zone, so that one would naturally expect some sort of bench to form, but the solution also goes on below this belt, so that one would not look for quite the same sharp outlines found on the ordinary benches.

The precise elevation of this contemporary horizontal platform is a matter of considerable importance. From my own and others' observations (see Macfadyen, 1930 ; Kuenen, 1933 ; Fairbridge, 1948 ; Fairbridge and Gill, 1947 ; and many others) it is claimed that the " normal " platform forms at the level of low-water springs. Exceptions are known ; pre-existing cavities in the rock (karst caverns and holes), lenticles of soft sand in the country rock, collapse structures, and so on, may all cause segments of the reef to be " abnormal." The occurrence of hard rock bands, gently dipping, may come by differential erosion to almost conform to the ideal reef height and shape, but may exhibit a gentle dip in one direction or another ; the effect being to institute considerable confusion (see, for example, the Sydney benches in gently-dipping Trias sediments—Jutson, 1939). Very exposed positions may result in shore " ramps," where the bench slopes gently up on the inside owing to the nature of the swash profile. However, when viewed overall, the " abnormalities " find local explanations, while the " normal " bench elevation tends finally to the height of low-water spring tides.

An interesting problem in this connection was first described from New Zealand by Bartrum (1916, 1935), where his " Old Hat " bench was already recognized by Dana and by Hochstetter. Its elevation is just below high-water level. Bartrum assumed that this is a contemporary bench, formed at the present stand of the sea, but in rocks of a particularly favourable sort and in fairly protected places ; the rock below high-water level is supposed to be always saturated in protective sea-water, while the overlying rock is subaerially weakened and prepared for removal by quite gentle waves. I cannot agree with this interpretation, and feel that the base-level of subaerial erosion is not high-water, but low-water, springs ; also the major role played by inter-tidal chemical processes should not be forgotten. Personally, I regard the " Old Hat " type of bench as a perfect example of the 10 ft. eustatic platform which was actually formed only about four thousand years ago, and is thus preserved in a surprisingly fresh state in favourable locations.

Admittedly, if we had not had the privilege of examining the phenomenon on many occasions under ideal conditions on limestone shores we might very well have failed to realize that there had been multiple eustatic stands of the sea-level during the last few thousand years, which have had the result of producing platforms a few feet above the present one—that is, at 2–3, 5–6, and 10–11 ft. above datum (for example, the present low-water spring-tide level (see Kuenen, 1933 ; Fairbridge, 1947A, 1947B, 1948, 1949 ; Teichert, 1947, 1948)).

It may thus be readily perceived that in regions of considerable tidal range, as in New Zealand around Auckland, all three of these higher benches would still be subjected to marine erosion to-day, and, in fact, may be very easily attributed to the effect of the sea at its present stand. In this way de Lapparent in France (1906), Jardine in Queensland (1925), Jutson in New South Wales (1939), Edwards in Victoria (1941), and Bartrum in New Zealand (1926, 1935) all speak of marine erosion as if it were selective at different heights of the tide and states of weather. At low tide we are supposed to get a " normal " or " ultimate " bench, at mid to high tide we find an " Old Hat " type of bench, and, finally, at storm-wave swash-height we see a notch called a "storm-wave " bench. In a quiet bay in Western Australia, however, I believe I could demonstrate *all four levels* in one and the


A.
"TEN FOOT" emerged beach
"TEN FOOT" Platform
Visor
REEF FLAT
AREA OF GREATEST WATER TEMPERATURE AND CARBON DIOXIDE VARIATION
DEEP WATER
AREA OF NEARLY CONSTANT TEMPERATURE AND CO_2 RANGE
HIGH WATER LEVEL
LOW WATER LEVEL
Maximum Undercut at mean sea-level
Very shallow water on Reef flat at Low-tide
Raised Reef Margin (Lithothamnium Rim — partly rock)
N.B. VERTICAL SCALE EXAGGERATED 10 TIMES

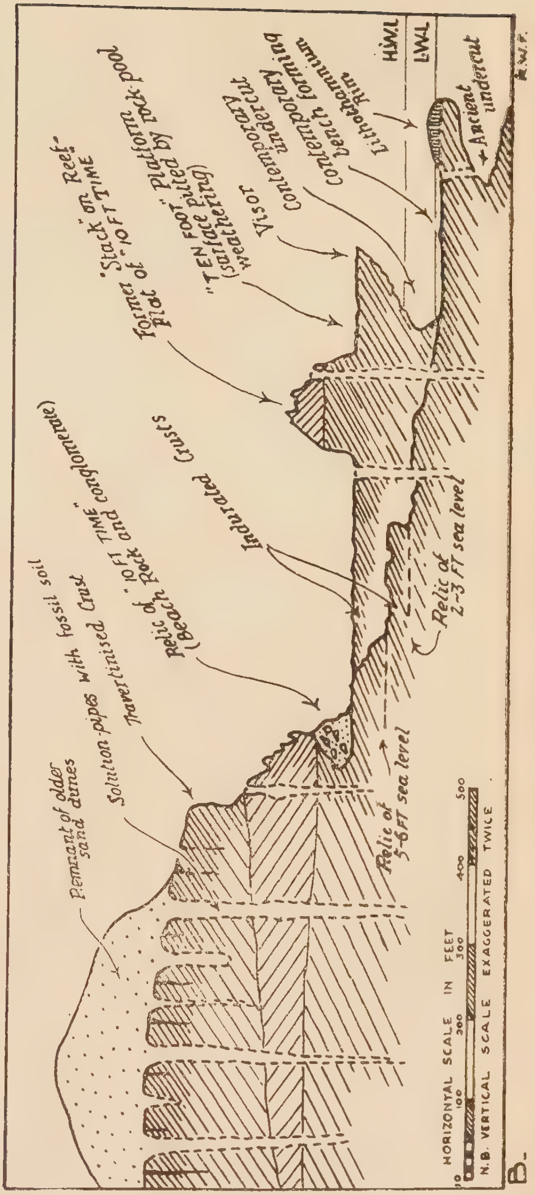

B.
Remnant of older sand dunes
Solution-pipes with fossil soil
Travertinised Crust
Relic of "10 FT TIME" (Beach Rock and conglomerate)
Indurated Crusts
Former "Stack" on Reef-Flat of "10 FT TIME"
"TEN FOOT" Platform (surface pitted by rock-pool weathering)
Visor
Contemporary undercut
Contemporary bench forming
Lithothamnium Rim
H.W.L
L.W.L
Ancient undercut
Relic of 5-6 FT sea level
Relic of 2-3 FT sea level
HORIZONTAL SCALE IN FEET
0 100 200 300 400 500
N.B. VERTICAL SCALE EXAGGERATED TWICE
R.W.F.

FIG. 1A.—Idealized section of a limestone reef flat, indicating how extreme physico-chemical conditions over the reef flat may facilitate chemical solution of the limestone down to the level of low-water springs, and operate at a maximum (in protected places) at mean sea-level, producing a deep undercut

FIG. 1B.—Idealized section of the "coastal limestone" cliffs at Point Peron, Western Australia, showing four post-Glacial bench levels cut by the sea at its various stands

same place, a spot where storm-waves never reach and where the tidal range is so small that all the higher benches or notches are practically preserved from wave erosion (Fairbridge, 1948, 1949; Teichert, 1948).

Taking the matter from another point of view, if we recognize that there have indeed been Recent higher sea-levels, we would expect to find the appropriate benches of those stands ranging up above the present " Old Hat " or storm-wave platforms. But, curiously enough, we do not. In places of considerable tidal range to-day, however (say, anywhere in excess of 10 ft. spring range), I would not be surprised if all the intermediate benches and notches are destroyed, so that all we see to-day is a single, large notch, the maximum incision of which stands at 12–15 ft. above present datum. This is a relic of the 10 ft. sea-level, with limited modification by all subsequent stands. It seems thus very likely that the " Old Hat " bench of protected waters in New Zealand is also the product of the 10 ft. sea-level; its resistant surface is not due to contemporary saturation by sea-water, but to induration at low-water level in early Recent times. And the " storm-wave " notches, which rise 5–10 ft. higher, are products of the same high sea-level, but in more exposed places.

For these reasons I am inclined to think that all the varied types of platforms attributed to contemporary marine erosion are nothing but " normal " platforms of various former sea-levels, some of which were broad and some were narrow and easily effaced, and which are subject to-day to varied exposures and types of weathering.

SOME EARLIER POINTS OF VIEW

The initial conclusion is that marine erosion on rocky coasts is very different from the text-book picture. We find a horizontal rock bench, tending towards an ultimate plane at the height of low-water spring tides. This is the base-level of subaerial decay. The mechanism of the erosion is more subaerial than marine, more chemical than physical. Wave action seems relatively unimportant below a few fathoms depth. Some investigation of the literature indicates that this is not really a new discovery, but merely that early work of the " chemical school " has been forgotten. I find the contrast between the two schools of thought on the subject of marine erosion—*i.e.*, the chemical versus the mechanical—so astonishing and so fundamental that a few appropriate quotations might be illuminating :—

Ramsay (1846), while being largely responsible for the theory of mechanical marine denudation, which was first outlined by de la Beche, conceived a platform of mechanical marine erosion which reached down only to a moderate depth; nevertheless, he expressed the opinion that subaerial erosion was a vital aid to marine planation by wave action. The term " abrasion " was coined for the mechanical process by von Richthofen (1886), who developed the idea further.

Lyell (1865) would consider the mechanical explanation and no other, saying, " No combination of causes has yet been conceived so capable of producing extensive and gradual denudation as the action of the waves and currents of the ocean upon land slowly rising out of the deep." Crossing the Atlantic, the teachings of Lyell appear to be reflected to some extent in the way in which the early American physiographers, such as Gulliver (1899) and Fenneman (1902), Davis (1909, &c.), Barrell (1913, &c.), and others make no mention whatever of subaerial agency in shore-line erosion. Summarizing the conclusions of this school, Douglas Johnson (1919/1938) states bluntly: "The vertical limit of marine denudation is a surface so low that wave action is no longer retarded by it" (a depth of 600 ft. or so in his opinion), and he finds the corollary that "there is no horizontal limit of marine erosion" (p. 234).

Returning, however, to the English physiographers of the last century, in specific reply to the wave enthusiasts, G. Maw (1866) expressed the opposite with precision and clarity. He was struck first by "the level surfaces of sea-coast reefs," indicating the base-level of rapid coast erosion at sea-level; the logical conclusion, of course, was that "the sea does no material work below the tidal range," except, of course, in certain very exposed places. The general tendency of marine erosion is towards a straightening of a coast-line, while drowning institutes indentations formerly occupied by subaerially formed valleys. Maw's accurate description of the normal contemporary horizontal bench or off-shore reef in England is a model which to-day could hardly be bettered elsewhere: "If we examine the sea-bed between high and low water mark, on any cliff-girt shore it is impossible not to be struck with the singularly level disposition of the reef surfaces extending seaward, which once formed the foundations of the old cliffs. Their general height would be a trifle above that of low tide, and any irregularities of surface will not exceed one or two feet. This well-marked lower limit to the erosive action of the sea is not confined to hard rocky coasts, but will be found to hold good in the softest strata."

The same thing was realized, too, by W. Whitaker (1867), who concluded: "The sea, therefore, does not by itself destroy the land, but is largely helped by atmospheric actions." Mellard Reade (1885) agreed, but claimed in fact that this was thoroughly understood by Hutton already a century before. On a previous occasion (1877) Reade had outlined his chemical experiments and calculations, concluding: "The chemical agency decomposes the matrix. . . . The ocean acts merely as a mechanical distributor of matter. . . . The action of subaerial erosion is . . . unlimited, except by sea-level."

Again, it is interesting to quote A. H. Green (1882): "The sea to a very large extent only finishes the work begun for it by subaerial denudating agents" (p. 206), and "It must be noted that the destructive action of the sea is confined almost entirely to the belt between high and low water mark. Within that space the rise and fall of the tides and the forces of the breakers grind down any loose matter exposed to their action. These agencies, however, cease to have any effect on the bottom covered by a moderate depth of water, and hence very nearly all the denuding work of the sea is coast denudation. The drifting of the rough sediment over the bottom by under-currents may produce some abrasion; but its amount cannot be very much" (p. 207). And yet again, Jukes-Browne (1893, p. 135): "Sea-waves can only act along one plane, and its currents, though able to erode soft sands and clays, can make but little impression on more solid rocks." And earlier, in more detail, he suggested that low-water mark was the lowest limit of subaerial forces; it was in fact "a line of non-erosion" below which accumulation would normally begin. "On a rocky shore the tendency of these conditions is to produce a horizontal or gently sloping platform, the outer edge of which corresponds to the line of non-erosion, so that its surface is bare at low water" (1884, p. 120).

In America, too, the same concept was expressed. J. D. Dana (1880, p. 676) says clearly: "The lower limit of erosion is above low-tide level." And, "The wearing action of waves on a coast is mainly confined to a height between high and low tides," though in this case Dana does not mention subaerial action. It is not without significance that Dana had travelled the Pacific extensively, including Australia and New Zealand, while Gulliver, Davis, Barrell, Johnson, and others formulated *their* ideas on the isostatically unstable, and therefore *abnormal*, coasts of New England (which are suffering post-Glacial reactions.)

Even Sir Archibald Geikie (1903, p. 575), while strongly emphasizing the forces of mechanical marine erosion, was careful to point out that: "Were it not for the potent influences of subaerial decay, the progress of the sea would be comparatively feeble." In Norway, recognizing the efficacy of subaerial erosion, Nansen (1905) believed that only such loosening and weakening could break down the extremely hard metamorphic (Caledonide) rocks, enabling the waves to move the debris to form the famous "Strand-flat."

Actual observations by W. von Zahn (1909) on the rocky coasts of Brittany and Normandy disclosed two distinct zones above and below mean sea-level: a "Schliffzone" or "Smooth Zone" below, affected by mechanical erosion; and a "Spritzzone," or "Brandungskarrenzone" (Spray-etched Zone), above, affected by chemical erosion. Kayser (1923) pointed out in any case that all three processes of purely marine erosion, biological, physical, and chemical are restricted to the absolute upper limit of marine erosion, and therefore tend to cut horizontally.

The rather special position of limestone in relation to chemical solution, as indicated above, has long been recognized, though exaggerated by Murray, Agassiz, Gardiner, and Crossland. Rapid solution of limestone in ordinary open sea-water certainly does not take place beneath the surface. On the other hand, recent observations by Macfadyen (1930), Kuenen (1933), and Fairbridge (1948) show conclusively that chemical erosion of limestone is accomplished by physico-chemical and/or biochemical processes of sea-water in its surface few inches near the shore. In this way broad, flat marine benches are eroded, the level of which is at the low-tide limit. Maximum erosion, in protected places—*i.e.*, where the actual sea-level is not mechanically raised by wave action—is at mean sea-level, and cliffs are deeply undercut at this level. As Kuenen says: "The solvent action is limited between the tidal range. The action of the sea is that of 'sawing' into the limestone."

Apart from the exceptional position occupied by limestone in this broad picture, the weakness of ordinary rocks to subaerial decay and their resistance to submarine mechanical attack has been specially emphasized by workers in New Zealand, where particularly fine examples of various benches were exposed. Noted in very early times by Dana (1849, 1872, 1880), a thorough explanation appears to have been first suggested by E. de C. Clarke in 1909: "Rock-benches are developed in many places along the steeper parts of the shore-line, more commonly in the sedimentary rocks, but also in the volcanics. These benches consist of shelves cut out of the solid rock, generally horizontal . . . it seems possible to ascribe the formation of rock benches to the co-operation of subaerial weathering, which causes the retreat of the cliffs, with marine transport, which removes the waste so-formed" (in Bell and Clarke, 1909, p. 30).

Bartrum has greatly developed this research into the New Zealand benches, and while I fancy that he did not fully appreciate the significance of eustatic changes, he clearly recognized the importance of subaerial weathering above sea-level. While the lower part of the cliffs, being permanently bathed and saturated in sea-water, would be completely protected from subaerial weathering, quite gentle waves would be sufficient to remove the debris, resulting in wide, flat benches (1916, 1935).

PENEPLANATION

Thus we see that it was a very different thing to imagine the sea operating mainly as a mechanical (and locally chemical) removal agent in the inter-tidal belt, from having its active mechanical erosion reaching right down to the ultimate wave-base. The sea could not act as an agent of regional peneplanation according to the former concept, but could according to the latter. With the former, the horizontal platform of erosion would eventually grow so wide that the sea could no longer wash away the debris but with the latter the waves would continuously be working downwards, permitting powerful waves to reach the cliff. It was this stumbling block which brought Douglas Johnson up against the old teachings of Ramsay, von Richthofen, and many others—*e.g.*, de Martonne, de Lapparent, Kayser, including Gulliver and Scott, in his own country, to name only a few outstanding names. De Martonne (1934, p. 671 *et seq.*) refers in fact to the Ramsay-Richthofen school versus the Barrell-Johnson school. The former believed that marine erosion acting on a stable continent would eventually form such a broad shallow abrasion platform that it would come to a standstill. The Johnson school imagined that an entire continent might in time be reduced to a submarine peneplain.

To quote Johnson's own words (1919, and even in his revised edition 1938, p. 163) : " If a land stands still long enough, the waves will reduce it to an ultimate abrasion platform . . . no matter how great may have been the original extent of the land." Theoretically true . . . perhaps, but R. T. Chamberlin (1930) has shown that if all the lands were base-levelled in this way the sea-level would rise 670 ft. ; so the production of such a horizontal peneplain is in any case impossible.

This Johnson concept is utterly unacceptable to de Martonne (1934, p. 677) and most continental European students. De Lapparent made the interesting suggestion that since wave action is far more impressive on the stormy coasts of Great Britain (and we might add Johnson's own New England shore-line) they should not automatically be regarded as normal (De Lapparent, 1906, p. 242). Even then he contended that the " normal " platform of marine erosion only ranges from high to low-tide level, though he called in storm-wave seasons, &c., to account for series of terraces (a phenomenon now adequately explained by eustatism). Park, in New Zealand, also made this point (1925), indicating that subaerial solvents provided a " powerful ally " to the " *more apparent* " forces of mechanical erosion.

In complete contrast to the fundamental teachings of the Lyell-Johnson school, the recognition of the slowness of marine erosion has apparently always been made in Europe. More recently, Novak (1938), Bourcart (1938), Francis-Boeuf (1938), and others have concluded that the continental shelf could not be due any more to Johnson's marine erosion than it could be exclusively due to Sir John Murray's sedimentary explanation (1888). Being left with subaerial erosion as the only satisfactory answer to the abundant evidence now available, from the topography (shown by sonic sounding), from the numerous basement rock outcrops, and so on, scientists are now looking for suitable explanations for this subaerial exposure, or successive exposures, of the shelf. Glacio-eustatic and tectonic explanations are both favoured, and a whole new field of instructive research is now opening up.

These two schools, therefore, thanks to the localities of their active protagonists, have more or less become associated to-day with Britain and America versus continental Europe.

Since Johnson's influence, for innumerable well-justified reasons in other connections, has been widespread in North America, his theory of marine abrasion has there become accepted almost without question. It is fortunate, however, that doubts have also been expressed on that continent. Wentworth (1927), as a result of careful studies in Hawaii, came to the conclusion that marine erosion cannot be a factor in peneplanation, only subaerial erosion could perform this colossal work. As a result of these and other researches considerable doubts are nowadays being expressed on the matter. Attention has also been drawn to another great fundamental weakness in all Douglas Johnson's coastal work, his omission to recognize fully the ever-riding control of eustatic changes which in Pleistocene and Recent times gave rise to multiple oscillating strand-levels (Shepard, 1937). Johnson (1933) made exactly the same error as many others in the Pacific in mistaking the 10 ft. eustatic bench as a storm-wave platform ; this is the same bench that is so commonly found all around closed bays where storm-waves never reach.

In conclusion, to summarize these remarks, we have made a protest against accepting the dogma laid down in many of the standard English and American text-books, following the teachings mainly of Lyell and Douglas Johnson, which appear, thanks, no doubt, to the geological constitution and geographical positions of the British Isles and the rugged coasts of New England, to have grossly exaggerated the forces of mechanical marine erosion and ignored the processes of subaerial and chemical decay in the formation of coastal benches or terraces. The works of European physiographers and those of New Zealand have been sedulously disregarded in this connection.

Finally, we deduce that the submerged and terraced shelf regions of the Pacific and other oceans are not the result of mechanical erosion operating to wave-base, but were cut subaerially and in the inter-tidal belt during periods of low eustatic sea-levels (or tectonically elevated continental rims). The short time that has elapsed since that last great emergence has prevented the accumulation of more than a thin veneer of post-Glacial sediment.

BIBLIOGRAPHY

BARTRUM, J. A. (1916) : High-water Rock-platforms : A Phase of Shore-line Erosion. *Trans. N.Z. Inst.*, Vol. 48, pp. 132–34.

——— (1926) : " Abnormal " Shore Platforms. *Journ. of Geol.*, Vol. 34, pp. 793–806.

——— (1935) : Shore Platforms. *Rept. Aust. & N.Z. Assoc. Adv. Sci.*, Vol. 22, p. 135–143.

BELL, J. M., and CLARKE, E. DE C. (1909) : The Geology of the Whangaroa Subdivision, Hokianga Division. *New Zealand Geol. Surv.*, Bull. No. 8, (n.s.), 115 pp.

BOURCART, J. (1938) : La marge continentale. Essai sur les régressions et transgressions marines. *Bull. Soc. Geol. Fr.*, 5 ser., Vol. 8, pp. 393–474.

CHAMBERLIN, R. T. (1930) : The Level of Baselevel. *Journ. of Geol.*, Vol. 38, pp. 166–173.

DALY, R. A. (1920) : A Recent World-wide Sinking of Ocean-level. *Geol. Mag.*, Vol. 57, pp. 246–261.

Dana, J. D. (1849) : *United States Exploring Expedition 1838–42*, Vol. 10 (Geology).

——— (1872) : *Corals and Coral Islands.* London (2nd. ed., 1875).

——— (1880) : *Manual of Geology.* New York, 911 pp.

Davis, W. M. (1909) : *Geographical Essays.* Boston.

Edwards, A. B. (1941) : Storm-wave Platforms. *Journ. of Geomorph.*, Vol. 4, pp. 223–236.

Fairbridge, R. W. (1946) : Coarse Sediments on the Edge of the Continental Shelf. *Amer. Journ. Sci.*, Vol. 245, pp. 146–153.

——— (1947a) : Our Changing Sea-level. *Scope* (Journ. Sci. Union., Univ. West. Aust.), Vol. 1, No. 2, pp. 25–28.

——— (1947b) : A Contemporary Eustatic Rise in Sea-level ? *Geogr. Journ.*, Vol. 109, p. 157.

——— (1948) : Notes on the Geomorphology of the Pelsart Group of the Houtman's Abrolhos Islands. *Journ. Roy. Soc. West. Aust.*, Vol. 33 (for 1946–47), pp. 1–43.

Fairbridge, R. W., and Gill, E. D. (1947) : Study of Eustatic Changes of Sea-level. *Austr. Journ. Sci.*, Vol. 10, pp. 63–67.

Fenneman, N. M. (1902) : Development of the Profile of Equilibrium of the Subaqueous Shore Terrace. *Journ. of Geol.*, Vol. 10, pp. 1–32.

Francis–Boeuf, C. (1938) : La probléme du plateau continental et des vallées sous-marines. *Rev. Géogr. phys. et. Géol. dynam.* (Paris), Vol. 11, No. 3, p. 254.

Geikie, A. (1903) : *Text-book of Geology.* London (Macmillan). 2 vols. (4th rev. ed.).

Gill, E. D. (1949) : Some Unusual Shore Platforms Near Gisborne, North Island, New Zealand *(Roy. Soc. N.Z.)* (In the press.)

Green, A. H. (1882) : *Geology, Pt. 1., Physical Geology.* London.

Gulliver, F. P. (1899) : Shore-line Topography. *Proc. Amer. Acad. Arts & Sci.*, Vol. 34, pp. 149–268.

Jardine, F. (1925) : The Development and Significance of Benches in the Littoral of Eastern Australia. *Repts. Gt. Barrier Reef. Comm.*, Vol. 1, pp. 111–130 *(Trans. Roy. Geogr. Soc. Aust., Qld.).*

Johnson, D. W. (1919) : *Shore Processes and Shoreline Development.* New York (Wiley), revised ed. 1938.

Johnson, D. (1933) : Supposed Two-metre Eustatic Bench of the Pacific Shores. *Congrés Int. Géogr., Cts. Rend.*, Paris, Vol. 2, pp. 158–163.

Jukes-Browne, A. J. (1884) : *The Students' Handbook of Physical Geology.* London, 514 pp.

——— (1893) : *Geology. An Elementary Textbook.* London.

Jutson, J. T. (1939 : Shore Platforms Near Sydney, New South Wales. *Journ. of Geomorph.*, Vol. 2, pp. 237–250.

Kayser, E. (1923) : *Lehrbuch der Geologie.* Stuttgart (Enke), Vol. 1, 740 pp. (7th & 8th ed.).

Kuenen, P. H. (1933) : Geology of Coral Reefs. *The Snellius Expedition*, Vol. V, Geological Results, pt. 2, 123 pp.

de Lapparent, A (1906) : *Traité de Géologie.* Paris (Masson), 5th ed.

Lewis, R. G. (1937) : *Studies in Earth Movements.* Loughton, Essex. (Publ. by the author), 173 pp.

Lyell, C. (1865) : *Elements of Geology.* London (Murray), 6th ed. rev.

Macfadyen, W. A. (1930 : The Undercutting of Coral Reef Limestone on the Coasts of Some Islands in the Red Sea. *Geogr. Journ.*, Vol. 75, pp. 27–34.

de Martonne, E. (1934) : *Traité de Géographie Physique.* Paris (A. Colin), 5th ed. (rev.), 3 vols.

Murray, J. (1888) : On the Height of the Continents and the Depth of the Oceans. *Scott. Geogr. Mag.*, Vol. 4, pp. 1–41.

Nansen, F. (1905) : Oscillations of Shore-lines. *Geogr. Journ.*, Vol. 26, pp. 604–616.

Novak, V. J. (1938) : On the Origin of the Continental Shelf. *Vestnik Kral. Ceská Spolectnosti Nauk (Prague)*, for 1937 (No. 17), 27 pp.

Park, J. (1925) : *A Textbook of Geology.* London, 2nd ed., 527 pp.

Ramsay, A. C. (1846) : On the Denudation of South Wales and the Adjacent Countries of England. *Mem. Geol. Surv. Gr. Brit.*, Vol. I, pp. 297–335.

Reade, T. Mellard (1877) : President's Address (1876). *Proc. Liverpool Geol. Soc.*, Vol. 3, pt. 3, pp. 211–235.

——— (1885) : Denudation of the Two Americas. *Proc. Liverpool. Geol. Soc.* (for 1884–5). (Pres. Add.)

von Richthofen, F. (1886) : *Führer für Forschungsreisende.* Hannover.

Shepard, F. P. (1937) : Revised Classification of Marine Shorelines. *Journ. of Geol.*, Vol. 45, pp. 602–624.

Teichert, C. (1947) : Contributions to the Geology of Houtman's Abrolhos, Western Australia. *Proc. Lin. Soc., N.S.W.*, Vol. 71, pp. 145–196.

——— (1948) : Late Quaternary Sea-level Changes at Rottnest Island, Western Australia. *Proc. Roy. Soc. Vic.*, vol. 59 (2), pp. 63–79.

UMBGROVE, J. H. F. (1946): Origin of Continental Shelves. *Bull. Amer. Assoc. Petr. Geol.*, Vol. 30, pp. 249–253.
WENTWORTH, C. K. (1927): Estimates of Marine and Fluvial Erosion in Hawaii. *Journ. of Geol.*, Vol. XXXV, No. 2, pp. 117–133.
WHITAKER, W. (1867): On Subaerial Denudation, and on Cliffs and Escarpments of the Chalk and Lower Tertiary Beds. *Geol. Mag.*, Vol. 4, pp. 447–454 and 483–493.
VON ZAHN, W. (1909): Die zerstörende Arbeit des Meeres an Steilküsten. *Mitt. Geogr. Gesell. Hamburg*, Vol. 24, pp. 193–284.

SUMMARY OF DISCUSSION

Dr. Shepard commented that steps across the continental shelf seemed from the study of a large number of charts to be practically the same in most parts of the world. As to storm-wave benches, tidal-wave investigations in Hawaii in 1946 had shown actual cuts 10 ft. or 20 ft. above normal sea-level. This was admittedly in soft material. But with repetition the same occurrence might take place in harder material. In general, said Professor Bartrum, there could be no doubt that surrounding platforms were uplifted.

Professor Bartrum replied to criticism by Dr. Fairbridge of his own results by commenting on a series of slides, including many New Zealand examples, confirming the conclusions of Gulliver and Fenneman. He pointed out that Dr. Fairbridge showed inconsistencies with his later argument, in attempting to homologize platforms 2 ft. to 8 ft. above sea-level with those below. The examples of " Old Hat " structure were illustrated. Such phenomena were encountered only in certain conditions, where the rocks were impermeable, free from close-spaced joints, amenable to weathering, and in sheltered waters. A local example was illustrated of a 96 ft. wide platform developed in Parnell Grit, having a gentle slope. The rocks were quite resistant when wet, but broke into pieces very readily on alternate wetting and drying. A series of other New Zealand examples was shown.

Professor Cotton attempted to sum up the conflicting points made by Dr. Fairbridge and Professor Bartrum. Everywhere that erosion occurred, he stated, two platforms were tentatively developed—one towards the sea showed normal sloping profile, while the high-water platform of Bartrum was also present, making its way in towards the land. In certain rocks the top platform gets ahead in its development and we find the " Old Hat " type of erosion. In other cases the lower platform develops at the greater rate, and we find the normal shore-line profile.

COMMENTS BY J. A. BARTRUM, AUCKLAND UNIVERSITY COLLEGE

Dr. Fairbridge's observations of shore platforms in rocks other than limestones, which have abnormal solubility compared with most other rocks, appear to be limited. On New Zealand shores there are hosts of examples of wide, gently-sloping subaqueous platforms which have the profile demanded by Fenneman, Gulliver, and others of their school. He also minimizes the corrosive potentialities of waves as compared with subaerial processes, but any observer can readily satisfy himself that, in normal rocks, given suitable tools, waves are extremely capable corrosive agents.

If, as Dr. Fairbridge maintains, the types of beach that I have termed the " Old Hat " and " Storm-wave " shore-platforms, which differ at times as much as 10 ft. in height, are to be referred to one and the same stand of sea-level, different processes must obviously have been involved in their formation. This does not seem consistent with Dr. Fairbridge's scheme of shore erosion, but it is so with my own.

I may remark here that in New Zealand there has been so much fairly recent block-faulting that correlation of any particular bench level with a particular phase of the Ice Age is peculiarly hazardous.

I should like to deal next with platforms of the "Old Hat" type which occur solely in *impermeable rocks free from open joints, readily amenable to weathering, and in very sheltered waters.* Their surface lies a foot or so below high-water level and they are the product, as Dr. Fairbridge correctly states, of subaerial weathering. I personally regard this surface as a level of permanent saturation below which subaerial weathering cannot proceed. Dr. Fairbridge, on the contrary would carry subaerial weathering down to the level of low water at spring tide. This manifestly would be possible for permeable rocks or those affected by close-spaced open joints, but, if waves have any appreciable corrosive power, the platform so produced would be eroded yielding a "normal" off-shore platform. If Dr. Fairbridge's views are correct and this platform is exposed at its present elevation merely by negative shift of sea-level, then its formation should be independent of the rock in which it is developed, provided that it was amenable to weathering. The nature of the joint fissures and the permeability of the rock should have no importance. The "Old Hat" type of bench, therefore, should not be infrequent; in actual fact it is by no means common.

"Storm-wave" platforms are developed only in fairly resistant rocks free from open joints at exposed locations such as headlands subject to attack by vigorous storm-waves and where reefs off-shore cause such waves to sweep upon the shore as surf (or waves of translation). Their surface is from a foot or two to as much as 8 ft. above high-water level, dependent on the vigour of the waves by which they are attacked, and, though initially rough in surface, in time may be smoothed down subaerially to the level of shallow pools of water lying on that surface.

Reasons which have led me to regard these benches as the product of the sea at its present level are—

(1) One can observe waves thundering on to these platforms during storms.

(2) The benches never pass far from the end of a headland towards a bayhead.

(3) When they do so, they decline in level away from the headland. Occasionally the change to a lower platform is abrupt. In these cases observation shows that the waves responsible for carving the platforms have had their vigour reduced after passing the headland; at times this reduction is because of deflection.

It is clear that the platforms are unlikely to occur in open-jointed rocks, which would be disrupted freely at varied levels by pneumatic and hydraulic pressures.

In conclusion, I would claim that Dr. Fairbridge has advanced no cogent reason for regarding platforms of the "Old Hat" and "Storm-wave" type as developed during a period when sea-level was higher than now. They therefore have no value in isostatic correlation of shore benches.

SYMPOSIUM ON WAVE ANALYSIS AND WAVE PREDICTION : WAVES AND TSUNAMIS

A SEISMIC SEA WAVE WARNING SYSTEM FOR THE PACIFIC

By W. B. Zerbe, U.S. Coast and Geodetic Survey

The heavy loss of life and property in the Hawaiian Islands that accompanied the seismic sea wave of 1st April, 1946, brought to the attention of scientists and engineers the need for the development of a system for quickly detecting and reporting these waves so that the Hawaiian Islands and other areas might be warned in sufficient time to be spared a repetition of such a disaster.

Although damaging waves have occurred in the past, progress in rapid communication and in instrumental development had not reached a point where a warning system was feasible. Soon after the earthquake of April, 1946, the Coast and Geodetic Survey undertook the development of the instruments and procedures required for the successful operation of such a system. These instruments, a visible recording seismograph with an alarm and a seismic sea wave detector, are now in operation, and sufficient progress has been made in the operation of the warning system to warrant reporting it to the scientific world.

It was obviously desirable that the occurrence of a major earthquake should be known at once. The records from photographic recording seismographs, which are in general use, are not visible until they are removed and developed. Those that produce a visible record would have to be watched continuously, which is impracticable. A seismograph that would in some way signal an alarm was therefore indicated. This need has been met by an electronic recorder that not only produces a visible record, but also sounds an alarm. The alarm is sounded when the amplitude of vibration of the light-beam is large enough to cause the beam to strike photo-electric cells placed near the ends of its swing. The alarm can be either audible or visual and it can be located in the station, the observer's quarters, or elsewhere. (This is a development of the electronic recorder described by F. Keller in the October, 1946, issue of *Transactions of the American Geophysical Union.*)

A recent development contains interesting added possibilities regarding the detection, location, and identification of submarine earthquakes. This involves the newly-discovered fact that these earthquakes sometimes generate low-frequency sound-waves peculiarly adapted for long-distance transmission through conducting layers of the sea-water. These waves pass into the ground structure of oceanic islands and can be recorded on special seismographs shortly after the higher-speed all-ground waves arrive.

The complete warning system, as at present developed, consists of four Coast Survey seismograph stations, the reports from which will definitely fix the epicentre of the producing earthquake ; a network of tide stations in the Pacific, some of which have seismic sea-wave detectors ; a seismic sea-wave travel-time chart ; and a high priority communication system.

The centre of the system is the Coast and Geodetic Survey seismograph station at Honolulu. Here all seismograph reports will be received, epicentres determined, alerts issued, and wave reports evaluated. Here it will be determined whether or not an alarm is justified. Only a small number of the quakes that occur in the ocean produce seismic sea waves, and not all sea waves are large enough to be dangerous. All must be treated with respect, however, by those involved in the system. Whenever the possibility of a sea wave exists, those charged with broadcasting warnings to the public and to military and other establishments will be notified to "stand by" so that no time will be lost in issuing a warning should it be found necessary.

The sequence of events that would set the system in operation will differ at different times. Ideally an earthquake would be detected by the seismograph station as soon as it occurred and be reported to the central station where the position of the epicentre would be determined. If the central station is the first to detect the quake, reports will be requested from the other stations. If the epicentre is found to be under the Pacific Oean where it could generate a sea wave, selected tide stations, favourably situated to intercept the wave before it reached the Hawaiian Islands, would be alerted to watch their gauges for evidence of a wave and report their findings. From the seismic sea-wave travel-time chart the central station can determine quickly what time to expect the wave in the Hawaiian Islands, and consequently how much time can be used in obtaining tide station reports. Though other places than tide stations may at times be asked for reports, tide stations are in a more favourable position to report usable information, for waves can be observed on the tide record that may otherwise go unnoticed. The fact that a wave is small at one place does not mean that it will not be large enough to be dangerous at another.

To take care of the possibility that a quake might remain temporarily undetected and that the first hint of a seismic sea wave might be the arrival of the wave itself, the Coast and Geodetic Survey developed a seismic sea-wave detector. This is a simple device with no moving parts except a column of mercury which moves to close an electric circuit. It makes use of the change of air pressure in a vertical pipe brought about when the rise and fall of the sea has the twelve to twenty minute period characteristic of a seismic sea wave. The detector screens out the rapid rise and fall of wind waves and the slow rise and fall of the tide, but automatically signals an alarm at a tide station upon the arrival of a seismic sea wave. Since most of the tide stations on Pacific islands are at military posts or communication centres where a twenty-four hour watch is maintained, an observer is always available to hear or see the signal. When the signal is observed the observer will check the tide record before alerting the Honolulu centre. Since the detector can be actuated by the first part of the wave motion a few minutes before the arrival of the destructive part, it can also be used to sound an alarm locally for the community or post in which it is located. (The instrument is described in greater detail in the January, 1948, issue of the *Coast and Geodetic Survey Journal.*)

Detectors have been installed at Honolulu, Hilo, and Midway, and another will soon be in operation at Palmyra Island. Others will be installed in the Aleutians. Places with large ranges of tide are being avoided because the rate of rise and fall of the tide must not approach too closely to that of a possible seismic sea wave.

The warning system is a co-operative undertaking. It binds into a network existing Coast and Geodetic Survey seismograph and tide stations by using facilities of the U.S. Navy, Army, Air Force, and Civil Aeronautics Administration. These agencies, along with the Coast Guard, the Territorial Government, the City of Honolulu, and others, will broadcast warnings by radio, siren, airplane, and any other means necessary to clear the beaches and waterfront areas of threatened communities.

Seismograph stations in the system are the Coast Survey stations at Tucson, Arizona; Sitka, Alaska; Fairbanks, Alaska; and Honolulu. To strengthen the system, the California University observatories at Pasadena and Berkeley will doubtless participate from time to time.

Tide stations that can be used for wave detection include three in the Aleutians, one each at Midway, Johnston Island, Palmyra Island, Pago Pago, Kwajalein, Hilo, Honolulu, and others, including numerous stations on the mainland of North and South America.

Although the warning system is not yet established in a complete form, it is in operation, and the quake of 8th September, 1948, in the region of the Tonga Islands provided a test of its efficacy. In this instance perhaps more time was consumed in obtaining seismograph reports than was desirable, but the time available to the central stations was sufficient to obtain reports from tide stations and others in the path of a possible wave. The travel-time chart showed that it would take a wave about 6 hours and 35 minutes to travel from the epicentre to Honolulu. As the time approached for the wave to arrive, planes took to the air in readiness to clear beach and waterfront areas, and all agencies were on the alert and ready to broadcast warnings. As the wave reports came in it became clear that though there probably was a wave, it was very small. The " Stand by " order was therefore rescinded and the " All clear " was given. When the record was later removed from the Honolulu tide gauge, it showed that a seismic sea wave had arrived about on time. Its height was 6 in.

So far as the public was concerned, the warning system operated satisfactorily, but from the point of view of those at the centre the test indicated the desirability of some adjustments and additional studies. The basic plan, however, proved to be well designed to accomplish the task for which the system was created.

WAVE ANALYSIS AND PREDICTION

By G. E. R. Deacon, Admiralty Research Laboratory, England

[*Abstract*]

As soon as continous wave records were examined the fact that the observed wave profile is the resultant of a number of wave trains had to be recognized, and methods had to be developed to detect and measure each invisible wave-train to obtain the wave-spectrum. The examination of many such wave-spectra and the relevant wind charts shows that a wind blowing over the sea produces waves of all lengths up to a maximum that depends on the greatest wind strength. These component wave-trains travel independently across the ocean with the group velocities appropriate to their periods; the short waves generated at the beginning

of the storm are overtaken and outdistanced by the longer waves produced when the wind is stronger, the separation between them increasing with distance (Barber and Ursell, 1948)(1). The first indication at a distant recording station is a narrow band of long low swell ; this is followed by shorter higher swell and the wave-band gradually broadens as the mean period decreases. The observed wave pattern at any place is generally a combination of waves generated by the local winds with swell components from remote sources.

To predict the wave pattern or surf breaking on a coast from meteorological charts and forecasts the effect of swell from each source must be taken into account and it is necessary to know how the wind energy is shared among the range of wave-lengths that are produced. Recent observations indicate that the amount of energy imparted to waves of a particular period depends on the difference between the geostrophic wind speed and the velocity of the wave and on the time during which the wind acts on the wave ; there is also a factor proportional to the wave period to allow for the increase with wave length of the capacity of a wave for absorbing energy without becoming unstable, and a factor inversely proportional to the wind speed to take account of evidence that there is an optimum wind speed for each wave-length, the growth of each of the shorter wave-lengths being decreased in turn as the rising wind strength causes such values to be exceeded.

Empirical methods based on such conclusions can be used with fair success to predict the wave-spectrum from hour to hour on the west coast of the British Isles, but there are many outstanding problems.

---

(1) BARBER, N. F., and URSELL, F. : The Generation and Propagation of Ocean Waves and Swell. *Phil. Trans. Roy. Soc.*, 240, 527 (1948).

By Authority: R. E. OWEN, Government Printer, Wellington.—1952.

Date Due

Library Bureau Cat. No. 1137